# SPONS'

# DICTIONARY OF ENGINEERING.

VOLUME I.

# SPONS'

# DICTIONARY OF ENGINEERING,

## Civil, Mechanical, Military, and Naval;

WITH TECHNICAL TERMS

IN FRENCH, GERMAN, ITALIAN, AND SPANISH.

EDITED BY

BYRNE AND SPON.

VOLUME I.

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK: 446, BROOME STREET.
1874.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

# PREFACE.

PREVIOUS to the publication of the present work, the want of a book of reference on Civil and Mechanical Engineering had long been experienced by the Engineer. A great deal of information of a useful kind had been recorded in the various Scientific Journals and Transactions of Engineering Societies, but it was given in a form not available for ready reference. The work so much needed is supplied, we trust, in this Dictionary of Engineering, written mainly by practical Engineers well acquainted with special branches of their profession, and whose names will be found in the List of Contributors.

Use has also been made of a large number of works devoted to Civil, Mechanical, Military, and Naval Engineering, and of the published writings of eminent Engineers.

Many subjects which ought perhaps to have a place in a complete work have been omitted, in the desire to confine the number of pages to something near the limit announced at the commencement; but we may be allowed to add that no other work on Engineering has been published which contains such a variety and amount of information on the same class of subjects in a collective form.

From the commencement of the work until August, 1872, the editorial department was conducted by Mr. Oliver Byrne, assisted by Mr. Ernest Spon; at that period Mr. Byrne ceased to be Editor, and the work has been completed under the direction of Mr. E. Spon.

Our thanks are specially due to G. G. André, Esq., C.E., for the careful attention bestowed on the subjects entrusted to him; and we also return our sincere thanks to the kind friends who have assisted in the compilation and revision of the various articles.

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# DICTIONARY OF ENGINEERING.

ABACUS, *and Instruments for Calculating.*

ABACUS. FR., *Tableau servant à calculer—Abaque;* GER., *Rechenbrett, Säulenplatte;* ITAL., *Abaco;* SPAN., *Abaco.*

A variety of more or less simple mechanical contrivances have been invented, almost from time immemorial, to simplify and facilitate the ordinary calculations of daily life; most of these contrivances, besides having little real utility, are so well known, and have been so frequently described, that a detailed description of them is here unnecessary; it is sufficient to say that the Chinese and other inhabitants of Central Asia still use these simple mechanical aids in performing calculations.

Napier devised a sort of abacus, or instrument for calculating, based upon the principle of rendering movable the columns of the ordinary multiplication table. The rods or bones of which this abacus is composed are termed Napier's rods or bones.

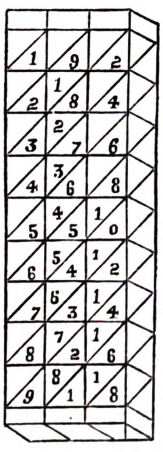
It is necessary to observe that each rod is divided into nine squares, and each square into two triangles, by a diagonal line drawn from the left lower angle. Fig. 1 represents one of these rods with the figure 3 in the right-hand triangle of the first square, zero and single figures, 1, 2, 4, &c., to 9, being always placed in a similar position on the other rods.

In Fig. 1 the second square from the top contains 6, or twice 3; the third 9, or three times 3; the fourth 12, or four times 3; and so on, to nine times 3, or 27; whence the figure at the top, and multiples expressed by single digits, are placed in the right-hand triangles, and the tens in the left-hand triangles.

It is clear that the faces which bear zero on the top must necessarily bear zero on all the triangles. For example, take three of the bones bearing on the top of their faces the figures 1, 9, and 2 respectively, and place them together, as shown in Fig. 2: the first line will read 192, the second $384 = 192 \times 2$, with this proviso, that *the figures placed between the same diagonal lines*, as 1, 2, *have to be added;* three times 192 reads 576 when the 3 and 2 between the diagonal lines are added, and so on to 9 times 192, which reads 1728 when the figures 9, 8, and 1, 1, between the diagonal lines are added. The apparent difficulty of this arrangement is by no means such as to deter any one from using Napier's rods, as a short practice suffices to render the use of those rods easy.

1.

2.

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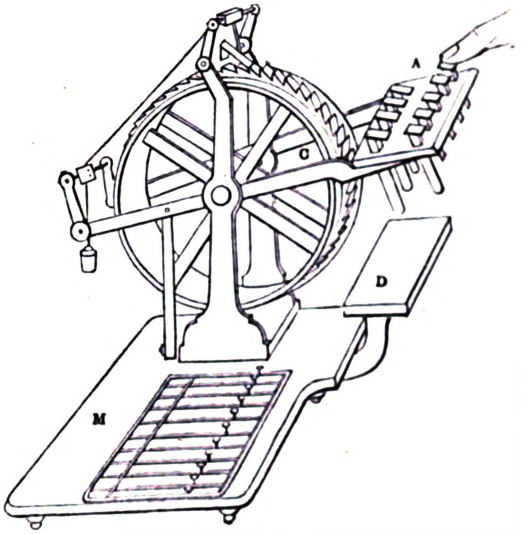



Augustus Barre's calculating instrument, Fig. 3, has a finger-board, A, furnished with ten keys of unequal length, each of which, in consecutive order, is marked with one of the figures 1, 2, 3, 4, &c., to 10. When the key which bears the number that an operator desires to add to another number, is pressed by the finger until it comes in contact with the stationary table D, the range of the angular motion given to the wheel C, which indicates the number to be added, is determined by the length of the key operated upon. The effect of pressing a finger upon the key, and lever C with which it is connected, is therefore to impart an angular motion to both

the wheel and the lever proportional to the digit which the key bears, that is, this motion will be smaller for the lower and greater for the higher digits. The moving of the key starts a click or catch, connected with a small weight, in consequence of which the wheel begins to turn; the motion is stopped as soon as the key pressed upon by the finger resumes its primitive position of rest.

*Calculating Instruments of Dubois and of Dunlop.*—The calculating instruments of Dubois assist in performing the elementary operations of arithmetic. In adding and subtracting, Dubois applies a series of small movable rules, upon the surface of which is painted or engraved the nine digits. In performing multiplication and division, Dubois makes use of an arrangement previously applied by Petit, in 1671. This arrangement consisted of engraving the figures upon rectilinear rods, similar to Napier's rods. There may be a real merit in applying old well-known methods in a useful manner, but this remark does not apply to Dubois' adaptation of Petit's arrangement; for Dubois' instrument, on account of its size, is far less commodious in use than many of the antique instruments which have been employed to effect a similar purpose.

Dunlop has introduced two calculators; his calculator No. 1, to perform multiplication and division, consists of a series of numbers, arranged in a tabular form made up of movable parts, so adjusted as to make it quite easy to find the simple multiples of any given set of figures; in reality this contrivance is an extension of Napier's method.

Form I., page 3, represents, on the left side, the inner rear side of the first page of Dunlop's tabulated form; the right-hand side represents the movable slips, which are partly folded up and covered by each other, while on the right ends they are open and a digit is to be seen thereon. The use of the said slips is sufficiently indicated by the printed inscriptions which they bear. It must be noted that the figures printed between brackets are in Dunlop's table distinguished by a red colour.

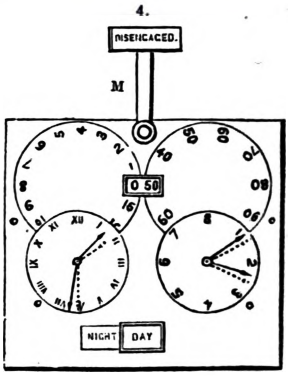
*Ex.*—Suppose one desires to know the price of 32½ yards of silk at 13*s.* 2*d.* a-yard; to perform this calculation one operates in the following manner: uncover the slip of the tens, No. 3, the slip 2 of the units, and slip ½ of parts of units, the end of which is visible in A, Form I.; place the sheets which cover those you are in want of for your purpose upon the left-hand sheet, and Dunlop's calculator will then exhibit itself to you as seen in Form II. At B C you read the multiplicand 32½, and in order to find the product by 13*s.* 2*d.*, look first upon the column marked 13*s.* on the lowest line; add together the two figures 0*l.* 6*s.* 6*d.*, 1*l.* 6*s.* 0*d.*, 19*l.* 10*s.* 0*d.*, total 21*l.* 2*s.* 6*d.*; this is the price of 32½ yards at 13*s.* Look next to the column marked 2*d.*, which gives a result of 5*s.* 5*d.*; add this to the former result, and the sum total will be found to be 21*l.* 7*s.* 11*d.*

The Dunlop calculator, No. 2, based upon the same principle, is designed for the calculation of weights.

The calculator, No. 3, is an instrument designed to facilitate the addition of partial products in cases when the multiplier is composed of several numbers; it consists of a box containing small slate rules movable in horizontal grooves; the partial products are written down upon these small slates, and since these are made to slide, it is easy to place the products in the order they respectively must occupy.

*Counters for Public Carriages.*—There exist two kinds of these instruments: namely, *graphical counters* and *purely mechanical ones*, all of which require the use of clockwork. The so-called graphical counters are so arranged as to note down the information, which it is of interest to the parties concerned to know, upon a piece of paper moved by clockwork; they are in fact self-registering instruments; but it is quite evident that such an instrument, since it requires the daily changing of the sheet of paper, would be a very inconvenient instrument to be applied by the proprietor of a large number of public carriages, as it is clear that it would require a considerable number of clerks to take down every night the papers put up in each respective carriage in the morning, and to note down the particulars registered automatically. The mechanical counters, on the contrary, are so constructed that it is possible to read off at a glance, by means of a mechanical contrivance of more or less complicate structure, the work performed during the day and the money received and to be accounted for. There exist contrivances of this kind wherein the graphical and mechanical arrangements are combined.

Various instruments both graphical and mechanical have been invented and used as automatic counters in carriages. We describe that of Bertrand and Addenet. The counter contrived by them is represented in Figs. 4, 5; the instrument is fixed on the carriage, behind the coachman's box, while towards the passengers, inside the carriage, are exhibited—1, a dial-plate of a clock or timepiece, indicating the time; 2, a dial-plate, provided with hands, indicating the number of kilometres, or distance run over, the hands being mechanically connected with the carriage wheels; 3, on the top of the said dial-plates a rectangular opening, showing the amount of the fare to be paid to the coachman; and 4, at the bottom of the instrument another opening is exhibited, bearing the words:—




or

Night, | Day,

since this refers to a different tariff of fares.

The figures which indicate the amount of the fare, are engraved on two discs, one of which, in the Paris carriages, marks the centimes, the other the francs. Motion is imparted to these discs by means of clockwork, from the timepiece already alluded to. At the time of starting, the counter indicating the amount of fare, reads, 0 francs 50 centimes, and the amount of fare due, runs

## TABULATED FORM.—I.

| | | |

up 10 centimes at a time. It is possible by this arrangement to use the instrument even for short distances. When a carriage is disengaged, there is exhibited outside, on the top, a small flag, M, *m*, bearing the word *disengaged*. The putting up of this flag by the coachman, has the effect, by means of proper mechanical contrivances, to disconnect the toothed wheelwork of the discs, and to bring the figures connected therewith, back to the first reading. If, with a view to fraud, the coachman should neglect this operation, the instrument is so arranged that it guards against his fraudulent intention, and compels him to account for all money received, on his return home.

5.

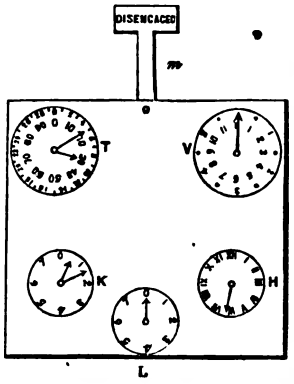



Fig. 5 represents an instrument employed in Paris omnibuses, and is a modification of that shown in Fig. 4.

T is a dial that shows the sum total; the outside figures on this dial represent francs, and the inner figures show the centimes.

L, a dial indicating how often the carriage has passed the barriers, and consequently shows the number of return tolls paid back to the driver, on his returning into the city.

V, a dial indicating the number of passengers; on the outside of this dial, figures show the total amount in francs, to which the constant 0.50 is added.

H, a dial indicating the time during which the carriage has been at rest.

K, a dial indicating the number of kilometres, or distance run over, while the carriage was unoccupied.

It is stated that the movements of the hands, of these different dials, are extremely simple, and may always be relied upon.

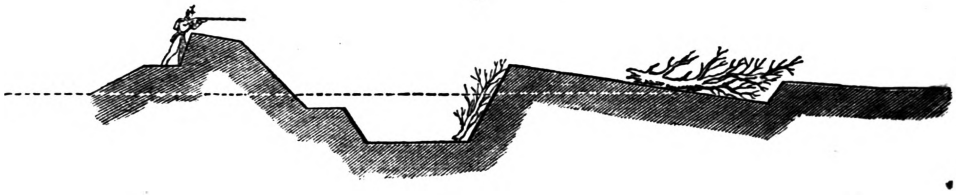
The mode of transmitting the motion from the carriage wheels to the instrument is new, and may be described thus:—

Suppose a wire placed, so as to be quite free to move, but in the most limited space possible, inside a flexible sheath; the wire is, in this particular case, spiral, of very tightly woven steel; the inside wire may then be taken to be a single central wire, which preserves its primitive length irrespective of the curve which the sheath makes, and also, irrespective of the variations of the ends of the sheath. The sheath, fixed to the counting instrument on the one hand, and to the axle of the wheels of the carriage on the other, has more or less play, according to the play of the springs which support the carriage; but the central wire always preserves the same length, and it is this wire which transmits to the kilometrical, or distance counter, the motion of the carriage-wheels. One of the front wheels of the carriage bears upon its stock an eccentric, which, at every revolution of the wheel, transmits an alternate motion to a bolt or beam placed on the axle-tree; upon this beam is fixed a piece which catches the wire contained in the sheath, and by this means a rack-wheel belonging to the distance counter is moved. Upon the evidence of several, who have been for many years connected with the Public Carriage Department in Paris, this arrangement, and every contrivance connected therewith, is pronounced to answer the purpose for which it was designed, in every respect. See COUNTER, *steam-engine*. PLANIMETER. SLIDE RULE.

ABATTIS. FR., *Abattis;* GER., *Verhau, Verhack;* ITAL., *Abbattuta, Tagliata;* SPAN., *Abatis.*

An abattis is generally constructed with large branches of trees, sharpened and laid with the points outward, in front of a fortification or any other position, to obstruct the approach of assailants. Abattis should be so placed as not to be exposed to the fire of artillery. In *redoubts* or entrenchments they are usually fixed in an upright position against the *counterscarp*, or at the foot of the *glacis*, the plane of which last is broken so as to permit of their being laid out of the enemy's sight, and so as not to interfere with the musketry fire from the *parapet* in their rear. See Fig. 6. Abattis is an excellent mode of blocking up a road; and when the branches are well

6.

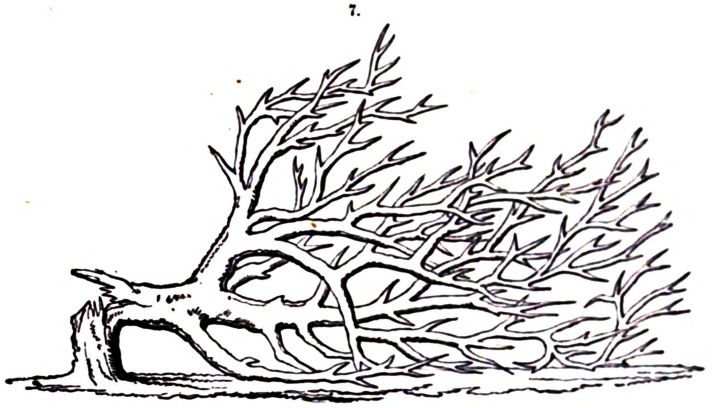


and properly placed, and interwoven one with the other, the disengagement of them is extremely difficult, and to form an opening sufficient for the passage of artillery, or even of cavalry, requires a long time. An abattis can easily be made by a few men, with half-a-dozen felling-axes and a cross-cut saw, and in a short space of time, if trees of sufficient size are near, or on the spot. It is more easily formed and gives more effective defence than *palisades*.

An abattis should not be planted out of musketry-range; for this and all other obstacles are to break up the order of the enemy's advance, to impede and keep him under musketry fire. The application of the abattis should be considered as purely local and not one of the common resources for securing entrenchments, such as *palisades*, *chevaux-de-frise*, and *fougasses*, the materials for the construction of these last being capable of conveyance from a distance. Hence localities may enable the engineer to obstruct a road, by dragging trees from the hedge-side and connecting the defences of a position, by levelling groups of trees with their branches towards the enemy.

Shrubby trees are not adapted to form a good abattis; they are easily forced and drawn out by the hand. Heavy trees with the trunk cut half-through form insurmountable obstacles; this last is called an *Entanglement*. See Fig. 7.

7.



**ABATTOIR.** Fr., *Abattoir;* Ger., *Schlachthaus;* Ital., *Macello;* Span., *Matadero.* A public slaughter-house in a city is termed an abattoir.

**ABSTRACTING DIMENSIONS.** Fr., *Epitomé pour servir de guide à bien prendre les dimensions;* Ger., *Einen Gegenstand aufmessen, Masse Zusammenstellen;* Ital., *Elenco delle misure;* Span., *Resúmen de dimensiones.* See Labour, *trained.*

**ABUTMENT.** Fr., *Culée, Butée;* Ger., *Widerlager;* Ital., *Coscia;* Span., *Estribo, Botarel.* See Arch.

**ABUTTING JOINT.** Fr., *Joint plat;* Ger., *Stumpfe Fuge;* Ital., *Commettitura piana;* Span., *Juntura plana.*

In carpentry, an abutting or a *butt joint* is a joint in which the plane of the joint is at right angles to the fibres, and the fibres of both pieces in the same straight line.

**ACCELERATION.** Fr., *Accélération;* Ger., *Beschleunigung;* Ital., *Accelerazione;* Span., *Aceleracion.*

Acceleration is the increase of velocity in a moving body, caused by the continued addition of motive force. When bodies in motion pass through equal spaces in equal times, that is, when the velocity of the body is the same during the period that the body is in motion, it is termed uniform motion, of which we have a familiar instance in the motion of the hands of a clock over its face; but a more correct illustration is the revolution of the earth on its axis. In the case of a body moving through unequal spaces in equal times, or with a varying velocity, if the velocity increase with the duration of the motion, it is termed accelerated motion; but if it decrease with the duration of the motion, it is termed *retarded motion*. A stone thrown up in the air affords an illustration of each of these cases, the motion during the ascent being retarded by the force of gravity, and accelerated by the same during the descent of the stone. All bodies have a tendency to preserve their state, either of rest or of motion; so that if a body were set in motion, and this moving force were withdrawn, the body, if unopposed by any force, would continue to move with the same velocity it had acquired at the instant the moving force was withdrawn. And if a body in motion be acted upon by a constant force, as the force of gravity, the motion becomes accelerated, the velocity increasing as the times, and the whole spaces passed through increasing as the squares of the times; whilst the proportional spaces passed through during equal portions of time will be as the odd numbers 1, 3, 5, 7, &c.; and the spaces passed over in any portion of time, taken as a unit, will be equal to half the velocity acquired at the end of such time. Thus, at the end of one second, the velocity of a body falling freely near the surface of the earth is said to be $32\frac{1}{6}$ ft.; at the end of 2 seconds, 2 times $32\frac{1}{6}$ ft.; at the end of 3 seconds, 3 times $32\frac{1}{6}$ ft.; at the end of 4 seconds, 4 times $32\frac{1}{6}$ ft., and so on; or generally, the velocity acquired by a falling body is equal to the product of the time of the body's fall in seconds by $32\frac{1}{6}$ feet, which may be expressed by the simple equation —

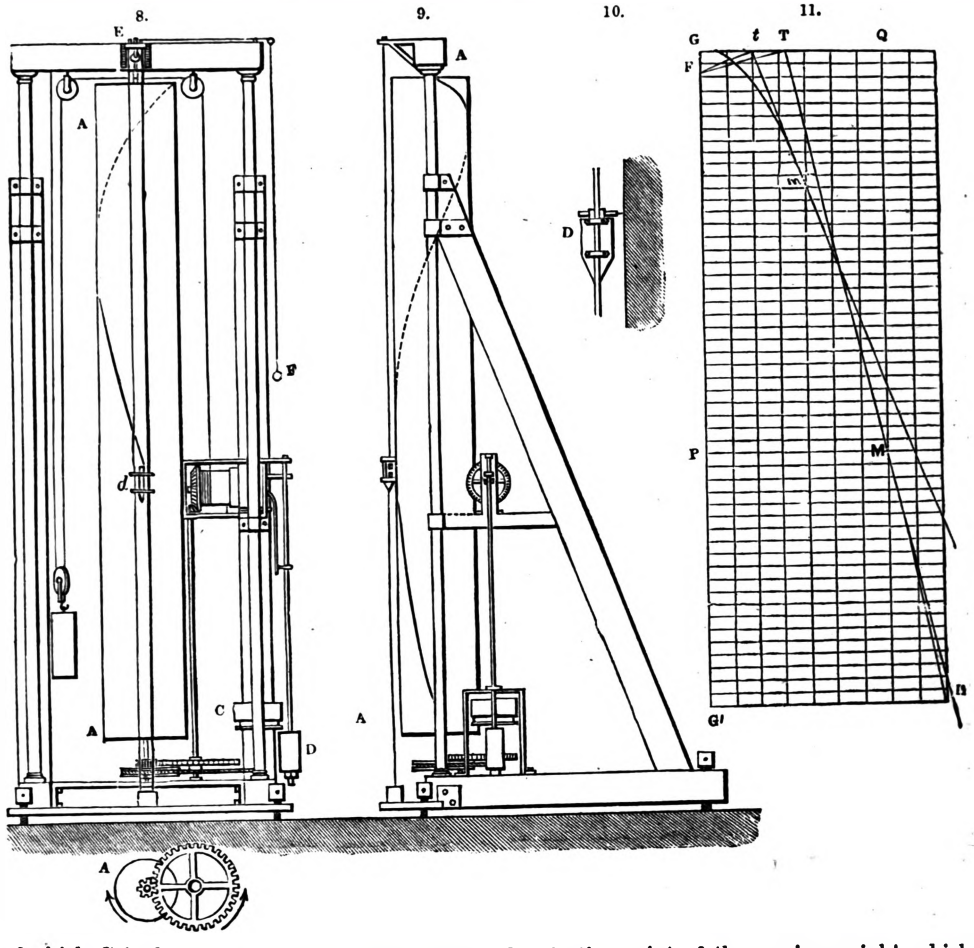
$$\text{(Velocity in feet)} = \text{(Time in seconds)} \times 32\tfrac{1}{6} \text{ or } v = t \times 32\tfrac{1}{6}.$$

The space described by a body in one second will be half of $32\frac{1}{6}$ feet $= 16\frac{1}{12}$ feet; because the velocity of the body in the middle of the time will be the mean velocity with which it moves during that time. In like manner, the space described by the body in 4 seconds, will be 4 times $2 \times 32\frac{1}{6}$ ft.; because $4 \times 32\frac{1}{6}$ ft. is the velocity at the end of 4 seconds, and therefore $2 \times 32\frac{1}{6}$ will be the mean velocity, or the velocity in the middle of the time. But 4 times $2 \times 32\frac{1}{6} = 16 \times 16\frac{1}{12} = 4^2 \times 16\frac{1}{12}$, that is, the space described by a falling body in 4 seconds is equal to the square of the time multiplied by the space described in 1 second. In the same manner, the relation of the space, $s$, in feet, and the time $t$ in seconds, is expressed generally thus, $s = t^2 \times 16\frac{1}{12}$.

*Morin's Apparatus for Demonstrating the Laws of falling Bodies, by means of Uninterrupted Indications.*—The apparatus constructed by Morin, according to the instructions given him by Poncelet, to effect this object, consists of a cylinder A A, Figs. 8, 9, moved by means of a vertical axis, set in motion by means of clockwork, regulated by the pendulum D. The surface of this cylinder is covered with a sheet of paper, a conical leaden weight, *d*, is made to move, guided and kept in its proper position, by guide-rods, at a small distance from the cylinder; to this leaden weight is attached a small hair pencil with a fine point, and this pencil being previously

dipped into colouring-matter, the point of it touches and marks the paper. This cylindro-conical weight, and the hair pencil, are represented on a large scale in Fig. 10. When an experiment is desired to be made with this apparatus, the weight *d* is kept at the upper part of the apparatus by a set of tweezers E; after the cylinder has been set in motion, and this motion has become uniform, the string F is pulled, by which the tweezer is unfastened, and consequently the weight *d* falls gliding down along its guide-rods, while the hair pencil marks simultaneously, on the surface of the paper placed upon the cylinder, a curved line, from which may be adduced the laws of the moving body.

When at the end of this experiment the paper is withdrawn from the cylinder, it will be observed that it contains two lines, one G Q, Fig. 11, a straight line, perpendicular to the axis of the cylinder (this line was marked out before the weight was allowed to fall); the other, a curve line G M H, to which G Q is a tangent. When to different points of this curved line, as for instance, M *m*, tangents are drawn, and when through the points T and *t*, where these tangents meet the straight line G Q, perpendicular lines are traced, it will be observed, that all these perpendiculars pass through one and the same point F. This is a property of the curve, known as the *parabola*, and the point F, wherein T F and *t* F meet, is the focus of the curved line. When from F, a straight line is drawn perpendicular to G Q, a perpendicular, G G′, is found, constituting the axis of the parabola,




of which G is the top, or summit. That point is the starting-point of the moving weight, which point could not be very readily perceived without this construction, since the vertex or summit of the curve is only exhibited by the contact of the curved line *m* M and the straight line G Q. Let us now examine any point M of the curve, and draw the rectangular co-ordinates M Q and M P with respect to the axes G G′ and G Q. The vertical line M Q represents the space, *e*, travelled over by the moving weight in a given time, *t*. The horizontal line M P represents the arc of the circle described in the same lapse of time by any point of the surface of the cylinder; let *r* be the radius of the cylinder, $\omega$ the velocity, which is taken for granted to be constant; the arc in question, therefore, has for its measure $\omega r t$. But since the curve described is a parabola, there exists between the co-ordinates of the point M, the relation

$$(\mathrm{M\,P})^2 = 2p\,(\mathrm{M\,Q}); \qquad [1]$$

calling *p* the semiparameter. By substituting for M P and M Q their respective values, we have

$$\omega^2 r^2 t^2 = 2p\,e,$$

whence

$$e = \frac{1}{2}\,\frac{\omega^2 r^2}{p}\,t^2. \qquad [2]$$

Equation [2] shows *that the space described by d is proportional to the square of the time.* The quantity $p$, is the double of the distance G F from the summit, or vertex, to the focus; by designating this distance by $h$, we have

$$e = \frac{1}{2}\,\frac{\omega^2 r^2}{2h}\,t^2,$$

while the acceleration due to the gravity is

$$g = \frac{\omega^2 r^2}{2h}. \qquad [3]$$

One might calculate $g = 32{\cdot}2$, from [3], but $h$ cannot be measured to a sufficient degree of accuracy. But we deduce [4] from [3] by putting $u$ for $\omega r$,

$$h = \frac{u^2}{2g}; \qquad [4]$$

that is to say, *the distance* G F *from the top of the parabola to the focus, is the height due to the velocity of any given point of the cylinder.* The parameter of the parabola becomes greater when the cylinder rotates more rapidly.

The law of the velocities may be deduced from equation [2], by taking the variable $e$ with respect to the time; whence

$$v = \frac{\omega^2 r^2}{p}\,t; \qquad [5]$$

it hence follows that the velocities are proportional to the time. Geometrical considerations establish the same law. For the curve G M H described by the moving-weight is the representative curve of the motion. By taking G P as the axis of $x$, and G G′ as the axis of $y$, the equation of the curve becomes

$$y = \frac{x^2}{2p}.$$

And the angular coefficient of the tangent, or the differential of $y$, with respect to $x$, is

$$\frac{dy}{dx} = y' = \frac{x}{p}. \qquad [6]$$

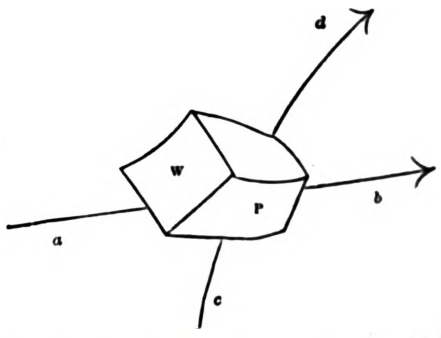
This angular coefficient is proportional to the velocity; now $x$ is proportional to the time, and therefore *the velocity is proportional to the time.* But equation [6] would not give exactly the value of the velocity; since, for $x = \omega r t$, we should have

$$y' = \frac{\omega r}{p}\,t,$$

a value differing from expression [5]. This is because the units of time and space are not represented by the same length, which condition ought to exist in order that the angular coefficient of the tangent to the curve of space, be equal to the velocity of the moving weight.

The units of work conserved in a body weighing W lbs., moving in any direction $a\,b$, or $c\,d$, straight or curved, with a motion being either retarded or accelerated, may be readily found when the velocity $v$, in feet a second, is known at P, any point of the path described by the body W. Fig. 12. The units of work accumulated in a moving body is equal to the square of the velocity in feet a second, multiplied by the weight of the body in lbs., and divided by $2 \times 32{\cdot}2$. The *mass* ($m$) of a body is a constant quantity at all heights and in all latitudes, while the weight W and the value of $g$ are variable; but $m = \frac{W}{g}$ under all circumstances. There is much uncertainty and error involved in the methods employed by philosophers to find the value of $g$ in different places. In this work, for the want of knowing better, $g$ is put $= 32{\cdot}2$ feet. That is, a body falling from a state of rest is supposed to be moving at the end of the first second with a velocity of $32{\cdot}2$ feet a second. When we say absolutely and without other explanation that the quantity $g$, which expresses the acceleration produced by gravity, is the measure of this force, we give an incorrect idea, since $g$ is in reality only the velocity imparted to or taken from a body by gravity during each second of its action, and the velocity which is expressed in feet cannot measure a force which should be compared with pounds. The product of the mass $m$, and the velocity $v = \frac{w}{g}v$, has received the name *momentum*; it is a conventional phrase, to which we attach no other signification than that of the product of the *mass* into the velocity imparted to or taken from it. If the weight $w = 193$ lbs. where $g = 32\frac{1}{6}$ ft., then the mass will be $= \frac{193}{32\frac{1}{6}} = 6$. In Paris $g$ is said to be $= 32\ 1817$ ft., in which place $w$ would be $= 193{\cdot}0902$ lbs.; but the mass remains unaltered, for $\frac{193{\cdot}0902}{32\ 1817} = 6$ also. A body W at the point P, weighing 230 lbs. moving in any direction with a velocity of 14 feet a second has accumulated in it 700 units of work, for $\frac{14^2 \times 230}{2g} = 700$.

12.

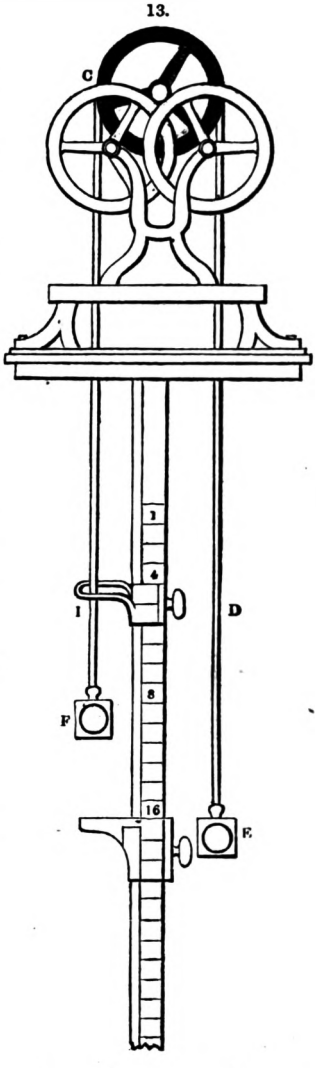



Suppose two weights, F and E, Fig. 13, weighing 4·9 lbs. and 7 lbs. respectively, to be connected by a cord, I C D, that goes over a fixed pulley C, as in *Atwood's machine*; the space through

which E must descend to acquire a given velocity, say 2·3 feet a second, may be found on the *principle of work* without direct reference to the acceleration of the bodies in motion. Thus, the units of work in $F = \frac{(2\cdot3)^2 \times 4\cdot9}{2 \times (32\cdot2)} = \cdot4025$; the units of work in $E = \frac{(2\cdot3)^2 \times 7}{2 \times (32\cdot2)} = \cdot575$; therefore, the total accumulated work in the bodies E and F at the required position = ·9775. Now if we suppose $x$ to be the space passed over by each of the weights, then the work of gravity on $F = 4\cdot9 \times x$; and the work of gravity on $E = 7 \times x$; as the work performed on F has been produced by the work of E, the work existing in the bodies is also represented by the difference of $7 \times x$ and $4\cdot9 \times x = 2\cdot1 \times x$. Therefore $2\cdot1 \times x = \cdot9775$, whence $x = \frac{\cdot9775}{2\cdot1}$ feet $= 5\ \frac{41}{70}$ inches.

Again, suppose a weight of 9 lbs. to act upon a weight of 7 lbs. over a pulley C, Fig. 13; the time taken for the greater weight to descend a given number of feet (100), and the common velocity of both bodies, may be determined on the *principle of work*, without direct reference to acceleration. For 9 lbs. − 7 lbs. = 2 lbs., and $100 \times 2 = 200$, the units of work in both weights. Then if $v$ be put for the velocity, the units of work in both bodies will also be expressed by $\frac{v^2 \times (7 + 9)}{64\ 4}$; whence $\frac{4\ v^2}{16\cdot1} = 200$, and $v = 28\cdot3725$ feet, the velocity at the end of 100 feet. Then the mean velocity = 14·1862, and $\frac{100\cdot}{14\cdot1862} = 7\cdot05$ seconds, the time of descent.

13.




ACHROMATIC LENS. Fr., *Lentille achromatique;* Ger., *Achromatische Linse;* Ital., *Lente acromatica;* Span., *Lente acromático.*

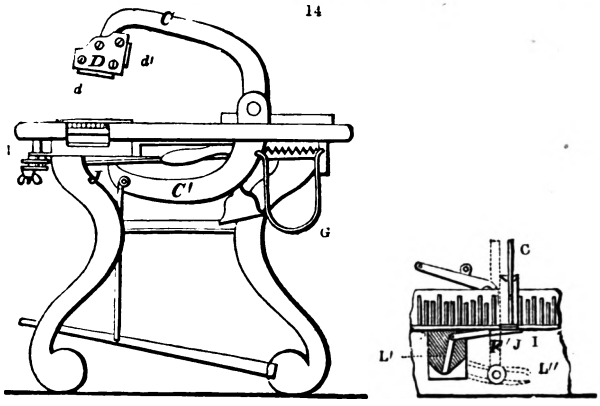
Those optical instruments and lenses which suffer the rays of light to pass through them, without decomposition, are called *achromatic*, which signifies without colour. See Optical Instruments.

ACRE. Fr., *Acre* (4840 *yards carrés*) ·404671 *hectare;* Ger., *Acker.—Morgen Landes* = 3291·2 *sq. yards;* Ital., *Jugero;* Span., *Acre* = 4046·87 *metros cuadrados.*

A measure of land containing 4 square roods, or 160 square perches, is termed an acre; the English acre of land contains 4840 square yards.

ADDRESSING MACHINE. Fr., *Machine pour faciliter l'impression d'un grand nombre d'adresses de lettres;* Ger., *Eine Vorrichtung damit man sehr schnell Briefen-adressen schreiben kann;* Ital., *Macchina da indirizzi;* Span., *Máquina para imprimir sobres, &a.*

14




An addressing machine is a machine for inserting the addresses of letters and other similar articles.

The addressing machine of N. E. & G. W. Warren, Fig. 14, consists of a curved arm, C, operating on a *platen* and worked by a treadle.

The curved levers or arms, C, C′, are operated by the bent spring G, in combination with the adjustable head D, and the faces *d*, *d*′. The *pall* F′, *rock-shaft* L′, slotted arm L″, and adjustable rod J, are worked by the *quad ratchet* I.

ADHESION. Fr., *Adhésion;* Ger., *Anziehungskraft;* Ital., *Aderenza;* Span., *Adhesion.*

Adhesion is the union of the surfaces of bodies when brought together, and is measured by the force which is requisite to separate them. Adhesion may be either natural or artificial. It is not to be confounded with *Cohesion*, with *Gravitation*, nor yet with the pressure of the atmosphere upon an external surface when the air is removed from beneath it. The power or degree of strength with which bodies unite is called their force of adhesion. Bevan found that a nail driven into Christiana deal required 170 lbs. to extract it; in green sycamore, it required 312 lbs.; in dry oak, 507 lbs.; in dry beech, 667 lbs. A screw holds three times as strongly as a nail of similar length, and in most light timbers a nail driven across the grain holds with twice the force of one driven with the grain. In oak and elm there is not so much difference. Well-glued surfaces of dry ash

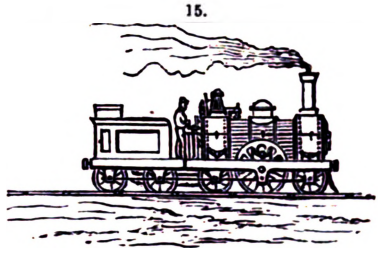
hold with a force of 715 lbs. to the square inch if the glue be new; Scotch fir with an adhesive force of 562 lbs. to the square inch.

The adhesive force on railroads may be estimated approximately from the simple expression $c \times t$, usually written $ct$, in which $c$ is the co-efficient of adhesion for the driving-wheels of the locomotive, and $t$ the weight of the locomotive in tons, which rest on the driving-wheels. The adhesive force of the driving-wheels, $c \times t$, must always be greater than the retractive force, $22{\cdot}4 \times t \times h$ nearly, in which $h$ is put for the vertical rise in feet for each 100 feet of road. Approximate results may be readily obtained by putting $c = 670{\cdot}$ when the rails are dry; $= 560{\cdot}$ when the rails are very dry; $= 450{\cdot}$ under ordinary circumstances; $= 314{\cdot}$ in wet weather; and $= 225{\cdot}$ in snow and frost. On horse-railroads, or tramways in large towns, $c$ varies from $300{\cdot}$ to $400{\cdot}$ in snow and frost. The influence of the resistances operating on railway trains in motion will be generally discussed when we treat of the experiments of MM. Krillemin, Guebhard, and Dieudonné. See DYNAMOMETER, *Railway Car*.

The force of adhesion will be better understood from its practical relation to friction, and to tractive and retractive forces.

Suppose the area (A) of one of the two cylinders of a locomotive = 400 square inches, Fig. 15; stroke (S) of piston = 1·5 feet; mean pressure (P) on the square inch = 96 lbs., and the diameter (D)

15.



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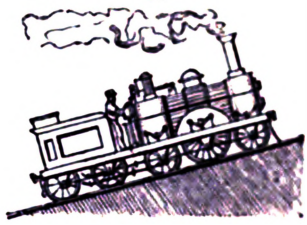


of the driving-wheels = 5 feet; then the tractive force = $\frac{A\,S\,P}{D} = \frac{400 \times 1{\cdot}5 \times 96}{5} = 11520$ lbs., $n$ being very nearly = $\frac{28\,M}{D}$ when M is the miles an hour and $n$ the revolutions of the driving-wheels a minute. Then the actual horse-power (H) of the locomotive, Fig. 15, = $\frac{n\,A\,S\,P}{11000} = \frac{A\,S\,P\,M}{376\,D}$. About 25 per cent. is generally allowed for the friction of the locomotive machinery and the power required to work the pumps.

Suppose a locomotive, Fig. 16, weighing 18 tons ($t$), to be placed on an incline rising 8 feet ($h$) in 100; the length (S) of the stroke of the piston = 2 feet; area (A) of piston = 320 square inches; the pressure (P) = 75 lbs. on the square inch; ($c$) the coefficient of adhesion = $560{\cdot}$, and the diameter (D) of the driving-wheels = 4·5 feet. Required the *tractive force*, *retractive force*, and the force of *adhesion*.

Tractive force = $\frac{A\,S\,P}{D} - 22{\cdot}4 \times t\,h = \frac{320 \times 2 \times 75}{4{\cdot}5} - 22{\cdot}4 \times 18 \times 8 = 7441$ lbs.

The retractive force $22{\cdot}4 \times t \times h$ being = 3225·6 lbs.

The base ($b$) for the rise 8 in 100 = 99·68, whence the *force of adhesion* = $\frac{c \times t \times b}{100} = \frac{560 \times 18 \times 99{\cdot}68}{100} = 10047{\cdot}744$ lbs.

But since 10047·744 is greater than 3225·6 lbs., the locomotive can ascend the incline with a tractive force of 10047·744 − 3225 6 = 6822·144 lbs., and without the driving wheels slipping.

Putting T for the weight in tons moved on wheels, and suppose T to include the weight of carriages on common roads, and the weight of carriages, locomotive, and tender on railroads, then on railroads the tractive coefficient ($k$) in lbs. to the ton in T varies from 4 to 8 lbs. On railroads in good condition, with axles well lubricated, $k = 4$ lbs. to the ton in T; on railroads and tramways under ordinary circumstances, $k = 7$; for roads not in very good condition, $k = 8$.

In ordinary traffic—

| | $k$ |
|---|---|
| On very smooth stone pavement .. .. .. .. .. | = 12 |
| On ordinary street pavements in good condition .. .. .. | = 20 |
| On some pavements and turnpike roads .. .. .. .. | = 30 |
| On turnpike roads newly laid with coarse gravel and broken stones .. | = 50 |

On common roads in bad condition, $k = 150$, and $k$ becomes as high as 560 on natural loose ground or on sand.

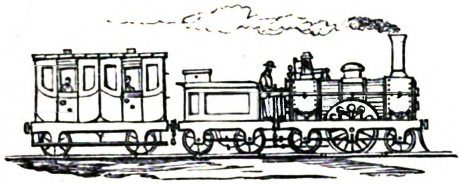
While comparing the lbs. in ($k$) and the tons in (T), it must not be forgotten that $t$ has been put for merely the weight of the locomotive in tons, which rests on the driving wheels. To illustrate this matter, let it be required to find the retractive force of a train (T) = 150 tons, Fig. 17, moving with a speed (M) = 25 miles an hour on a horizontal line of railroad in the best condition, or when $k = 4$.

The retractive force is nearly = $T\,(k + \sqrt{M}) = 150\,(4 + \sqrt{25}) = 1350$ lbs.; this force must be less than $c \times t$, the *adhesive force*. The actual horse power (H) of the locomotive is nearly equal to $\frac{M\,T}{375}\,(k \times \sqrt{M})$. Let it be required to find the horse-power (H) necessary to

draw a train (T), Fig. 18, = 137 tons, up an incline of ($h$) = 9 feet in 100, with a speed (M) of 25 miles, when $k$ = 6.

$$H = \frac{M\,T}{375}\,(22\cdot4\,h + k + \sqrt{M}) = \frac{25 \times 137}{375}\,(22\cdot4 \times 9 + 4 + \sqrt{25}) = 1923\cdot5.$$

17.



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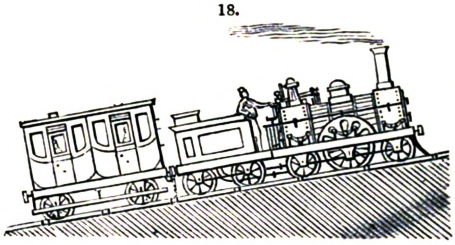

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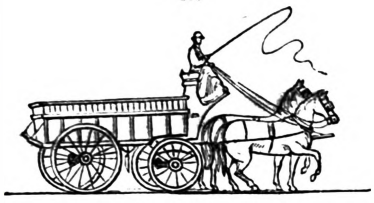

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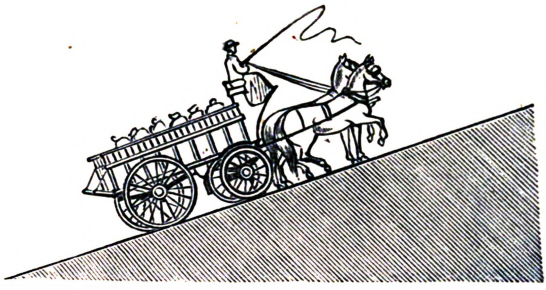


The adhesive force $\frac{c\,t\,h}{100}$ must be greater than T $(22\cdot4\,h + k + \sqrt{M})$. If ($d$) be put for the number of consecutive working hours of a horse, ($v$) the velocity in feet a second, and ($t'$) the weight of a horse in lbs., then, Fig. 19 we have the approximate formulæ—

$$F = T\,(k + \sqrt{M});\ v = 1\cdot466\,M;\ \text{and}$$

$$F = \frac{550}{v\sqrt{d}} = \frac{375}{M\sqrt{d}} = \text{the ability of a horse.}$$

Whence the tractive abillty (F) of a horse running five miles an hour in four ($d$) consecutive hours $= \frac{375}{5\sqrt{4}} = 37\cdot5$ lbs. Lastly, let it be required to find the tractive force F of a load T = 10 tons, to be drawn M = $2\frac{1}{4}$ miles an hour, up a turnpike road, Fig. 20; $h$ = 8 feet in 100, $k$ = 50, the road being newly laid with coarse gravel. The following formulæ will approximately apply:—

$$F = T\,(22\cdot4\,h + k + \sqrt{M});\ M = \cdot682\,v;$$

$$\text{and } F = \frac{550}{v\sqrt{d}} - \frac{t'\,h}{100}.$$

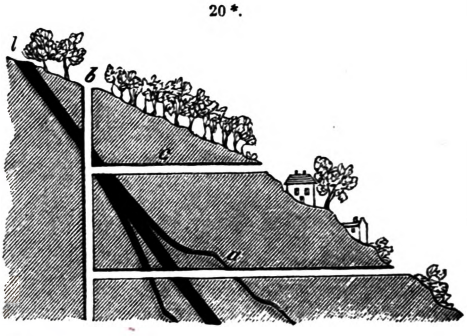
$$F = 10\,(22\cdot4 \times 8 + 50 + \sqrt{2\cdot25}) = 2307 \text{ lbs.}$$

Suppose a horse to weigh $t'$ = 1000 lbs. and to work continually, $d$ = 1 hour, up this turnpike road; the tractive ability of this horse will be $\frac{375}{2\frac{1}{4}\sqrt{1}} - \frac{1000 \times 8}{100} = 86\frac{2}{3}$ lbs. Hence the number of horses required $= \frac{2307}{86\frac{2}{3}} = 27$ nearly.

ADIT. Fr., *Passage, Galerie (d'écoulement d'eau dans les mines)*; Ger., *Zugang, Stollen*; Ital., *Adito*; Span., *Galeria de una mina.*

The horizontal opening by which a mine is entered, or by which water and ores are carried away is termed an adit. The woodcut represents an exaggerated section of part of the underground workings of a mine; *b* is the shaft, *a* and *c* the adits, and *l* the lode; *c* is called the shallow adit and *a* the deep adit.

20*.




ADZE. Fr., *Herminette*; Ger., *Krummaxt, Hohleisen*; Ital., *Ascia*; Span., *Azuela.*

An adze is a tool for chipping, formed with a thin arching blade, and its edge at right angles to the handle. The edge is only bevelled on the inside. See Hand Tools.

AFTER-DAMP. Fr., *Mofettes*; Ger., *Böses, oder tödtendes Wetter*; Ital., *Mefite*; Span., *Mofeta.*

Choke-damp is often termed *after-damp*: it is the carbonic acid gas which accumulates in mines

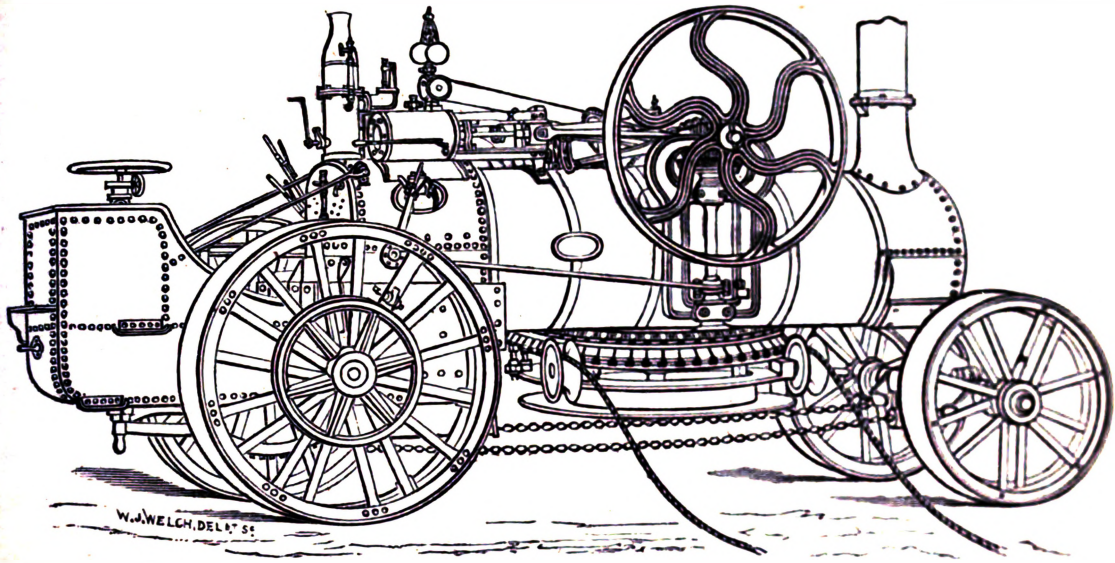
and wells; this gas is called choke-damp because it often destroys life by preventing the respiration of air. See ANEMOMETER.

AGRICULTURAL IMPLEMENTS. FR., *Ustensiles employés à l'agriculture*; GER., *Landwirthschaftliche Geräthe*; ITAL., *Macchine ed utensili agricoli*; SPAN., *Utiles agrícolas*.

Many of the agricultural implements introduced in this article are not only well-arranged to effect the purposes for which they are designed, but, at the same time, they will be found, as regards construction, to interest civil engineers generally, either in suggesting the application of some peculiar mechanical principle, or in pointing out combinations of machinery which may be found useful beyond the limits of the field or farmyard.

The annexed woodcut, Fig. 21, represents a portable steam-engine and windlass combined, as constructed by C. Burrell; the windlass has a single *sheave* of 5 ft. diameter, round which the rope

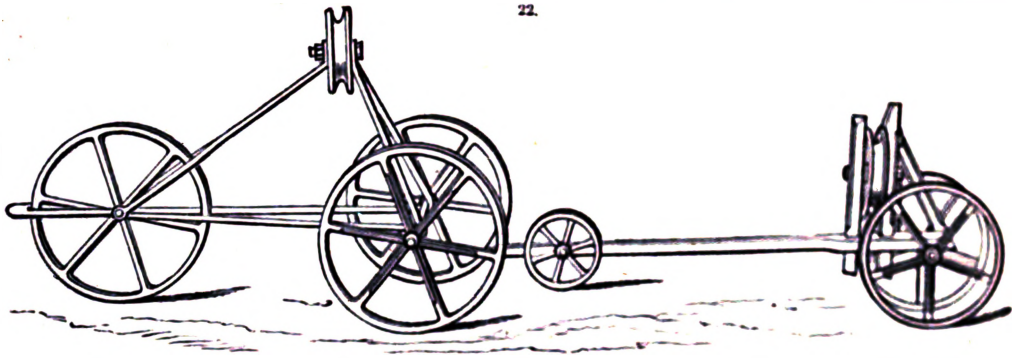
21.




passes, and it is formed of a double series of small leaves, which on the least pressure clasp and hold the rope until it takes the straight line on the other side, when the clips freely open and liberate the rope. By this simple appliance all crushing and short bends, which are so detrimental to the profitable use of wire-rope, are entirely avoided; this, coupled with the fact that on each passage of the implement the rope is only twice bent, and then only round large diameters, will at once show this system of using wire-rope to be most advantageous. The small leaves are made of chilled cast-iron, which is not liable to much wear, but the leaves, when worn, can be replaced at a trifling cost. The power is conveyed to the windlass by an upright shaft from the crank shaft.

Fig. 22 represents the rope porters to be used along with the engine for agricultural purposes just described: these porters are placed along the fields at intervals of 40 yards, thereby

22.



keeping the rope entirely off the ground. The outside ones are mounted on three wheels, so as to allow them to be moved by the rope.

Fig. 23 represents what is termed the anchor, which is shown attached to the working apparatus. This anchor is made to resist the side strain of the implement worked, by the cutting of the disc wheels into the ground. The anchor is moved along the headland by the motion of a 5-feet *sheave*, which is turned by the ploughing rope, and as the plough goes away from the anchor, the sheave winds up a rope stretched along the headland and keeps the anchor opposite its work. The frame is made entirely of wrought iron. As the disc can be steered in any direction, the

anchor may be moved along a crooked headland. The box at the back is intended as a counterpoise to prevent the anchor being pulled over when heavy work is being done. This machine is managed by a boy, who also attends to the shifting of the rope porters.

23.

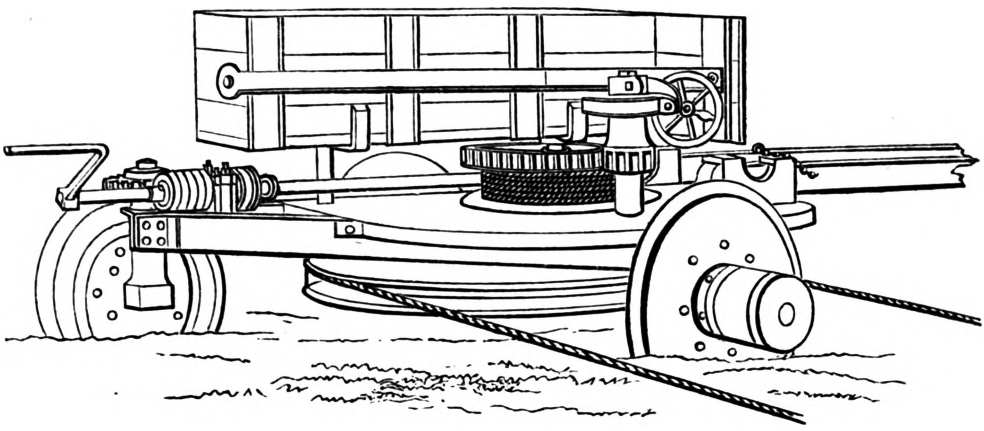


Fig. 24 represents what, for agricultural purposes, is termed a liquid manure distributor, designed by W. Crosskill. A pump and hose being fixed to this cart it may, when yoked, be often found useful as a watercart, either for the transport of water, from a distant river, well, or canal, or it may be applied to water roads and streets.

24.

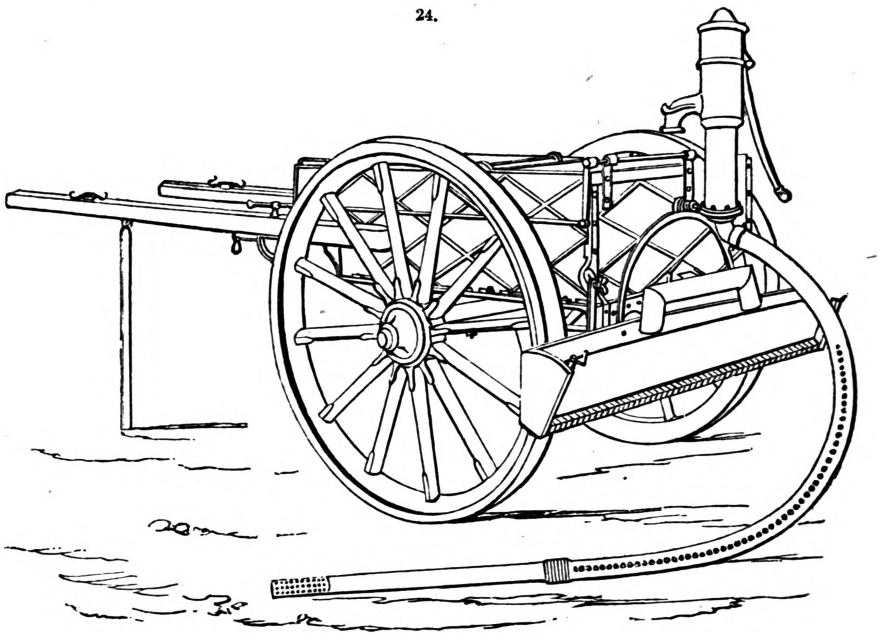


Fig. 25 represents the portable farm railway of W. Crosskill, which may sometimes be of use to contractors, engineers, or builders.

Fig. 26 represents an improved horse gear or horse-power for driving machinery; it has a strong cast-iron *bed-plate* supporting the bearings of the horizontal ground shaft, and the step for the vertical shaft. To prevent accident, and as a protection from dust and dirt, the whole of the gearing, and working parts, are encased by a cast-iron dome cover, secured to the bed-plate, by screw bolts. The main top bearing is adjustable by set screws, so as to ensure uniformity of wear, and steadiness of motion.

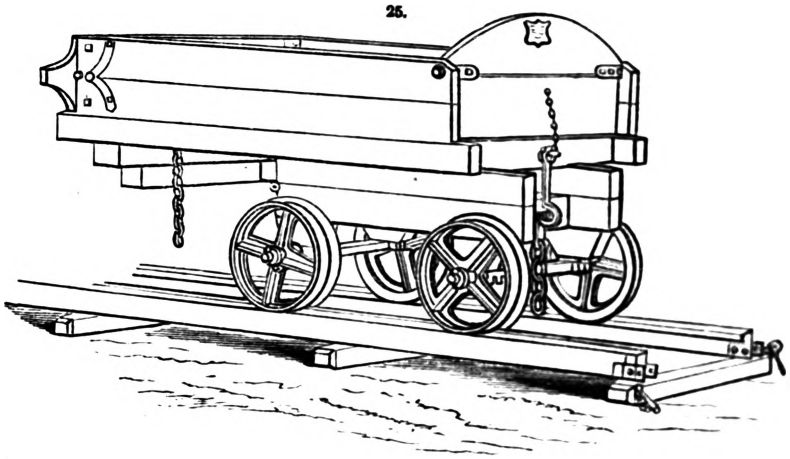
Fig. 27 represents the bone-rasping and grinding mill of Picksley, Sims, and Co. It is simple in construction, strong in its working parts, and produces at the first operation, 25 per cent. more dust than the ordinary bone mill at present in use.

The working process is as follows:

Unbroken bones are thrown into the hopper, fall upon the cutting bed, and are pressed by feed rams against the teeth of revolving cylinders in rapid motion.

The reduced bones fall into an oscillating or revolving *riddle*, attached to the mill, in order to separate them into the two usual qualities, namely, dust and half-inch bones.

25.



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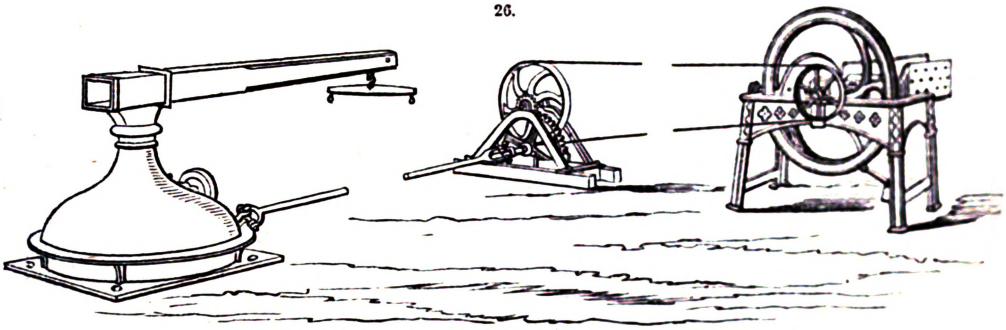
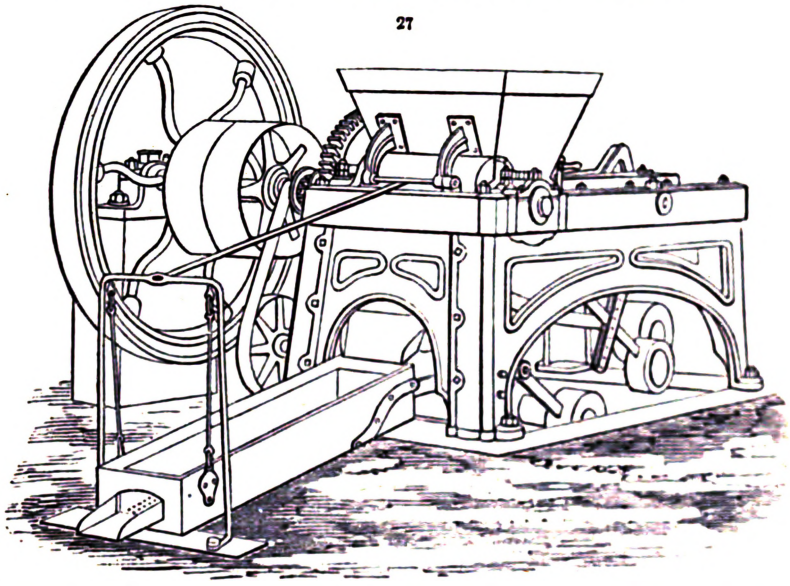


27



The coarser portions of bone, which do not pass through the riddle, are then, by means of elevators, thrown again into the hopper, and re-ground with the unbroken bones. At the first operation the following proportions are obtained :—

Dust. . . . . 45 per cent. of the entire quantity ground.
½-inch bone . . 30 " " "
Coarser matter (to be re-ground) 25 per cent.

This mill is adapted for grinding every description of bones, irrespective of size and quality.

The feeding of the mill is regulated alternately by the driving shaft, and by a counter balance-weight placed beneath the mill; by this contrivance, the bones are pressed against the cutters without any undue *strain* being thrown on the working parts, and the possibility of breakage is diminished.

The mill has an apparatus attached, for passing small pieces of iron which may accidentally get into the hopper with the bones.

Unusual facilities are given for keeping the cutters sharp and in working order, as they can be readily disengaged, sharpened on a grindstone, and replaced in working order by any intelligent labourer.

*Directions for Proper Use.*—The mill should be set level upon a solid foundation of stone, and secured by means of screw bolts.

The caps on the bearings should be firmly screwed down, merely leaving sufficient play for the shafts to revolve without unnecessary friction.

The driving strap should be placed tightly upon the *driving pulley*, and the mills driven at the following speeds:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2-horse | power mill, | 250 | revolutions a min. | 8-horse | power mill, | 150 | revolutions a min. |
| 4-horse | do. | 225 | „ „ | 10-horse | do. | 150 | „ „ |
| 6-horse | do. | 200 | „ „ | 12-horse | do. | 125 | „ „ |

The oil boxes on all the shafts should be kept well supplied with oil.

When the knives require grinding they may be readily removed from the cylinder, by using a key of $\frac{5}{8}$ steel as a drift; this operation is performed by holding one end of the drift against the small end of key which keeps the knives in place, and striking the other end with a hammer until the key is backed sufficiently to be withdrawn; by this means the spiral segment which keeps the knives in place can be disengaged, and when the segment is removed, the knives are liberated, and may be taken out.

In replacing the knives, care should be taken that the keys are so driven in, that they may clear the frame at the head and point, and the knife edge should pass the cutter bar without touching.

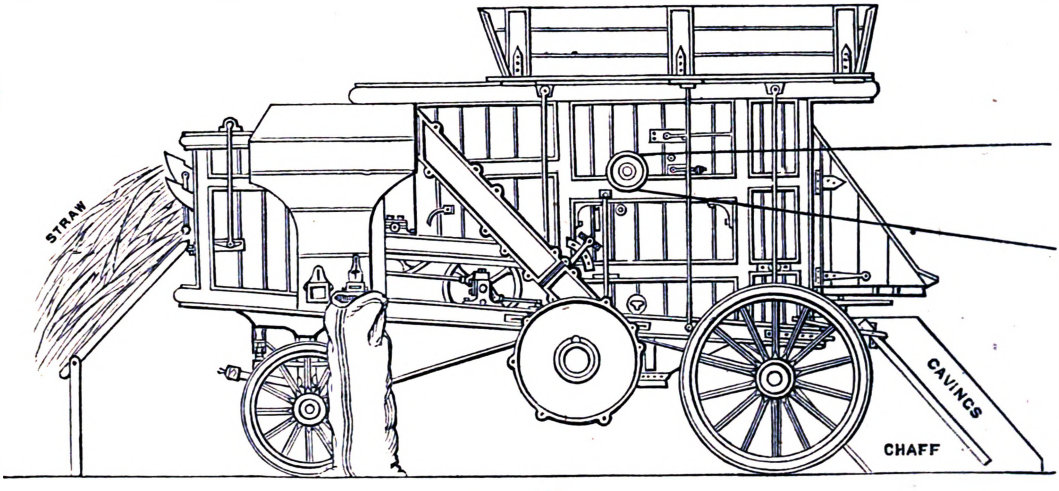
The knives should be ground daily, as upon their sharpness depends the satisfactory working of the mill, both as to quantity and fineness of the dust produced.

As the knives wear, they should be kept up in the slots by strips of wood being placed underneath them.

Before starting it is desirable that the mill be inspected, to see that all bolts and nuts, are secure, and the knives firmly fixed in their places, and that the cylinder has sustained no injury in a previous operation.

The chief aims of the application of mechanical power, as a substitute for manual labour, are to effect improvements in the results of labour, and to render them less expensive. The use of the hand-flail to separate and detach corn from its ears is now pretty generally superseded by the thrashing machine, which, in its main features, may be called a contrivance devised to supersede by mechanical means the use of the hand-flail, and thus to economize at the same time both time and labour, and secure a less wasteful mode of separating the corn and chaff from each other. A thrashing machine essentially consists of a rapidly revolving cylinder, with raised edges or beaters parallel to its axis and standing out from its surface. The cylinder or drum is covered by a concave surface at some two or three inches distant from the surface described by the edges of these revolving beaters. A feeding board extends radially and horizontally outwards from the cylinder, and near its termination are placed two feeding rollers, which, in revolving towards one another, not only rapidly draw the straw forward, but also hold it from going too fast, which, under the action of the beaters, would be liable to happen. The beaten straw, with the chaff and grain lying loose among it, is delivered on the floor behind the cylinder, and the operations of separation by fork, riddle, and fanner may be afterwards performed by hand; but in the more improved modern machines these operations also are effectually done by mechanical contrivances, usually, so connected with the thrashing machine as to operate with it at the same time and by

28.

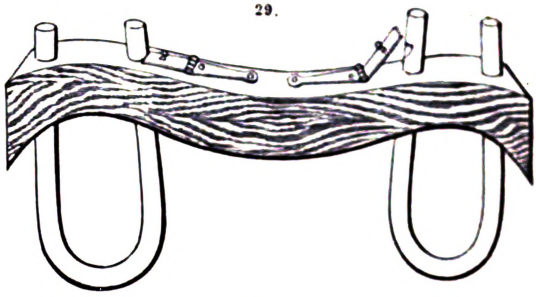



the same motive power. The annexed woodcut, Fig. 28, represents a portable, combined, single blast thrashing, straw-shaking, riddling, and winnowing machine, constructed by Picksley, Sims, and Co.

Many minor improvements in agricultural implements have been recently made. We insert brief descriptions, illustrated by woodcuts, of some of the most useful.

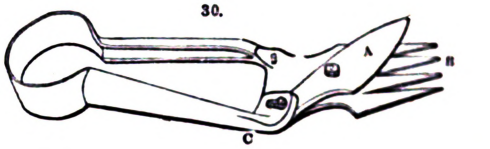
*An improved Ox-yoke.*—The mortise through the bow of an ox-yoke greatly weakens the bow, and the key sometimes gets misplaced, and even lost, although attached to the yoke by a leather thong; the thong may break, and just when the key is most needed it becomes of no practical use. To remedy this is the design of the improvement shown in Fig 29. Two hinged plates are secured to the top of the yoke, as shown in Fig. 29, the free ends engaging with notches cut in the bow, and holding them securely in place until they are forcibly raised by hand.

29.



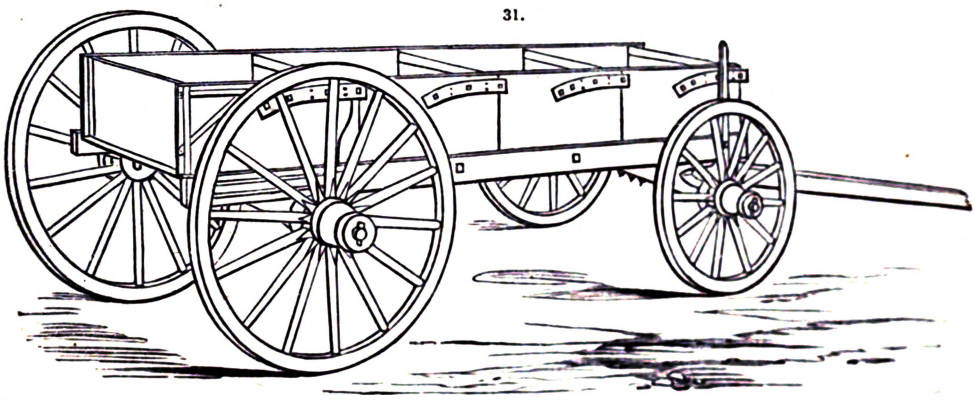
*Sheep Shear.*—Fig. 30 represents *an improved sheep shear*, the movable cutter A pivoted to the face of the stationary cutter B, which is divided into fingers, or bars, each one presenting a cutting edge to the action of the movable blade. A slot in the free end of the spring handle, and a screw in the end of the vibrating cutter, with a stop on C, on the opposite side of the plate B, governs the throw of the blade. The forks of the plate readily enter the matted fleece, thus facilitating the operation of shearing, and the action of the blade ensures a drawing cut, requiring less power and producing a cleaner cut than ordinary shears. The form of the cutter and its throw can be regulated to suit any hand; this implement may serve also for clipping horses.

30.

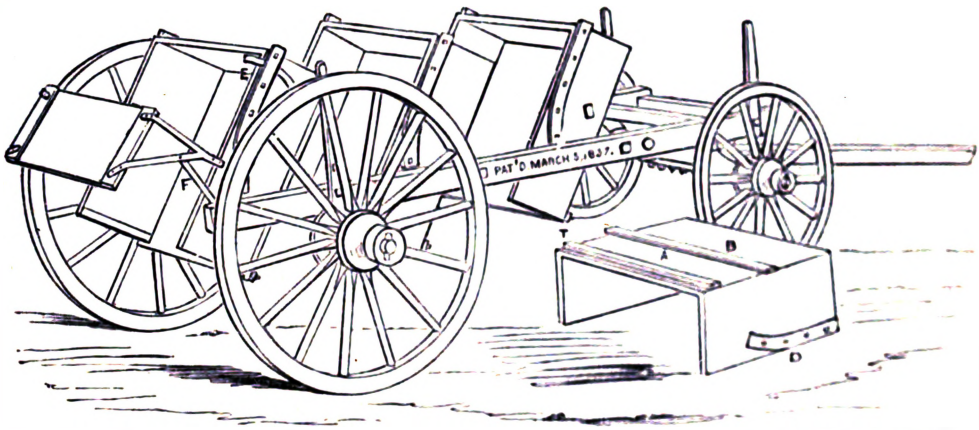



*A wagon*, the contents of which could be readily emptied or discharged by its attendant, has long been a requirement, not only upon a farm, but more especially in the grading of streets, railways, and the like. Dumping, as hitherto performed, required a considerable exercise of muscular force when the discharge of the materials was from a four-wheeled wagon; the operation

31.



32.

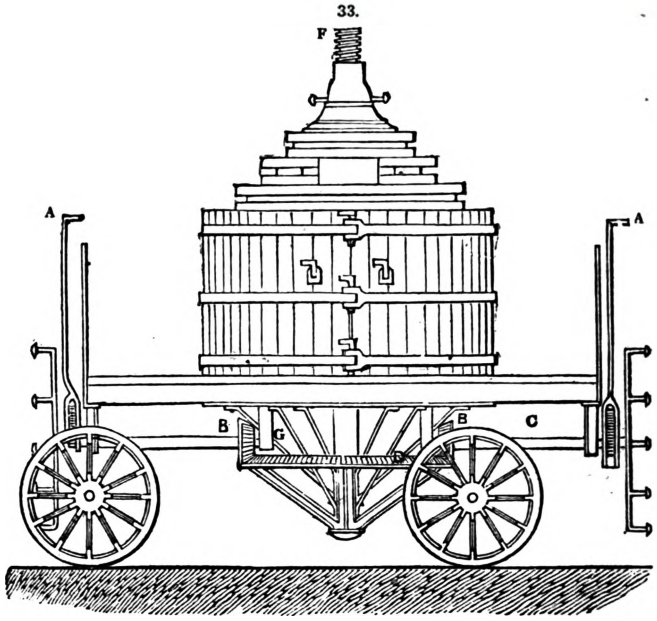



also, comparatively speaking, involved great loss of time. The wagon, represented in Figs. 31, 32, appears to be effectually secured in dumping. The essential features of the invention will be

readily understood by a reference to the cuts. This wagon consists of a box, or body, composed of separate sections arranged in line with each other between the longitudinal sides, or bed-pieces, of the wagon frame, each section being pivoted or suspended upon these bed-pieces by suitable laterally projecting trunnions or pivots, so that it may be placed in a horizontal position to hold the materials, or it may be tilted with its open or rear end downwards to discharge the materials therefrom. When the sections are all in a horizontal position, as shown in Fig. 31, the sections are connected by suitable latch-pieces, or catches, at their sides, in such a way as to be firmly held in place. These sections may be filled by shovelling, or other means, in the same manner as an ordinary wagon or cart box. When it is desired to dump or discharge the load placed upon the wagon, the several sections composing the box are disconnected, and the sections are tilted as before mentioned, and shown in Fig. 32, whereupon the materials drop from the sections by their own gravity, and the sections are consequently emptied with great speed and facility.

*The Châtillonais.*—For the convenience of such agriculturists as are in the habit of making wine, cider, or perry, we give a cut, Fig. 33, and short description of a very useful press known as the *Châtillonais*, and highly esteemed in France. The mechanism is placed on wheels, and the machinery for pressing is below the trough. The pressing is so performed that free passage is given to the screw; the ratchet brace A, placed upon the handle of the axis C, is provided with 14 crank-handles, and by means of C moves B, which has 90 teeth; the axis of the latter carries a conical cog-wheel with 10 teeth, and this wheel grips into the large wheel D provided with 102 teeth; the multiplication is therefore $6{\cdot}43 \times 10{\cdot}2 = 65{\cdot}586$, that is to say, that the screw makes one revolution for 65·586 strokes or revolutions of the handle. The average diameter of the screw is 0·1015, and its thread is 25; this gives for the inclination of the thread $\alpha = 4° 30'$.

33.




The radius of the handle is $0^m$ 40 at most, that is to say, L = 0·4, $r$ = 0·05075, $n$ = 65·586, $\alpha = 4° 30'$, and $\nu = 5° 42'·40$. If these figures be substituted in the general formula we have the following result:—

$$P = F \times \frac{0{\cdot}4}{0{\cdot}05075} \times 65{\cdot}586 \times \frac{1}{tg\ 10° 12' 40'' + 1{\cdot}33\ tg\ 5° 42' 40''} = 1651{\cdot}5\ F.$$

Place for F 15 kilogrammes for one man, or in all 30 kilogrammes, P = 49545, and, neglecting friction, we have at least 40,000 kilogrammes of useful work.

$$\frac{49{\cdot}545\ \text{kil.} \times 0{\cdot}025}{65{\cdot}586 \times 2\pi \times 0{\cdot}4 \times 30\ \text{kil.}} = 0{\cdot}25.$$

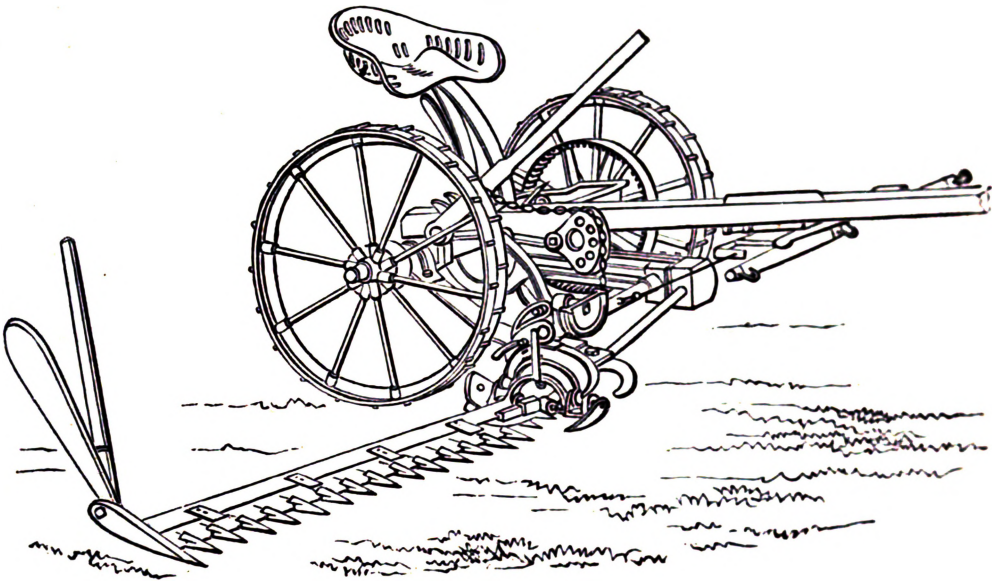
When the friction is taken into consideration, we have only 0·207, or about 21 per cent.

*The improved Reaper of Messrs. Howard.*—In this reaper, Fig. 34, double concentric cams are employed, the one for directing the motion of the gatherers, and the other for guiding the rakes; the former being caused to drop down into the grain, in order to bring it up to the cutters, and then to rise again, so as to clear the cut grain on the platform, which is removed by the rakes governed by the second annular or concentric cam. The platform is hinged to the centre, by a kind of *drag bar*, and the delivery is effected by a central shaft, which is driven by a *pitch chain*, thus enabling light gearing to be used for operating the cutter bar. The mower of Messrs. Howard, also, possesses several improvements, amongst which we may point out a simple mode of lifting and varying the angles of the cutter. The "Clipper Mower," which we illustrate, has many peculiarities. The pole is independent of the draught, as the tractive strain is exerted through a sliding attachment on the under side of the pole. By this system there is a tendency not only to draw the machine directly forward, but at the same time to lift the shoe off the ground. The inside shoe and its attachments are so arranged that the fingers and knives can be changed from a level cut to an angle of thirty degrees, while the machine is in motion.

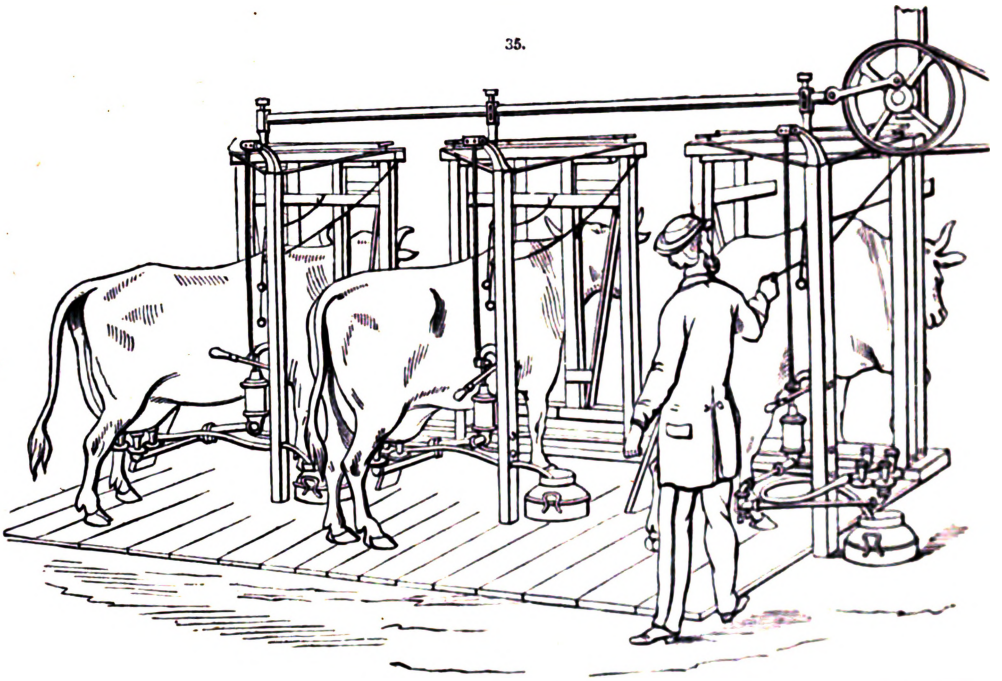
*Colvin's Cow-milking Machine.*—The engraving, Fig. 35, represents three cow-milking machines, operated by power, and attended by one man; two of these machines are shown, each milking a cow, and one exhibits the milking completed, and the cow turned back out of the way, so that the cow that has been milked may pass out to make way for another to come into the stall to be milked, so as not to stop the power while changing the cows. The stanchion is the same as any ordinary stanchion, with the exception that it opens out, to let the cows pass through, and facilitates the changing of them; in this manner, cows can be very quickly brought to the machine. The operation occupies less time than it would take to go to the cow in the yard, or stable; the cows

soon learn to come to the machine if fed a few times while being milked, or by being enticed through giving them some salt. The milk is conducted by suitable tubing into large cans partially sunk in the floor; three machines are sufficient to milk sixty cows in the time it would take six men to milk them by hand. The moving power is imparted to the machines by hand, by a dog running in suitable gear, or other prime mover. The milkers are worked by pumps, the pistons of which are driven by power; they are attached by a jointed iron pipe to allow of the movement of the cow forward, backward, or sideways, always adapting itself to her motions; the teat-cups are made of corrugated india-rubber closely enveloping the teats, and will fit any cow. The pumps oscillate in such manner as to give the natural motion of a calf sucking, or to impart the motion of the human hand while milking; the space between the elastic diaphragm in the milker and the pump being filled with water, which, in working the pumps, oscillates in the tube, and produces a vacuum at each alternate stroke. By the working of this machine it is clear that no dust nor any dirt can fall into the milk.

34.



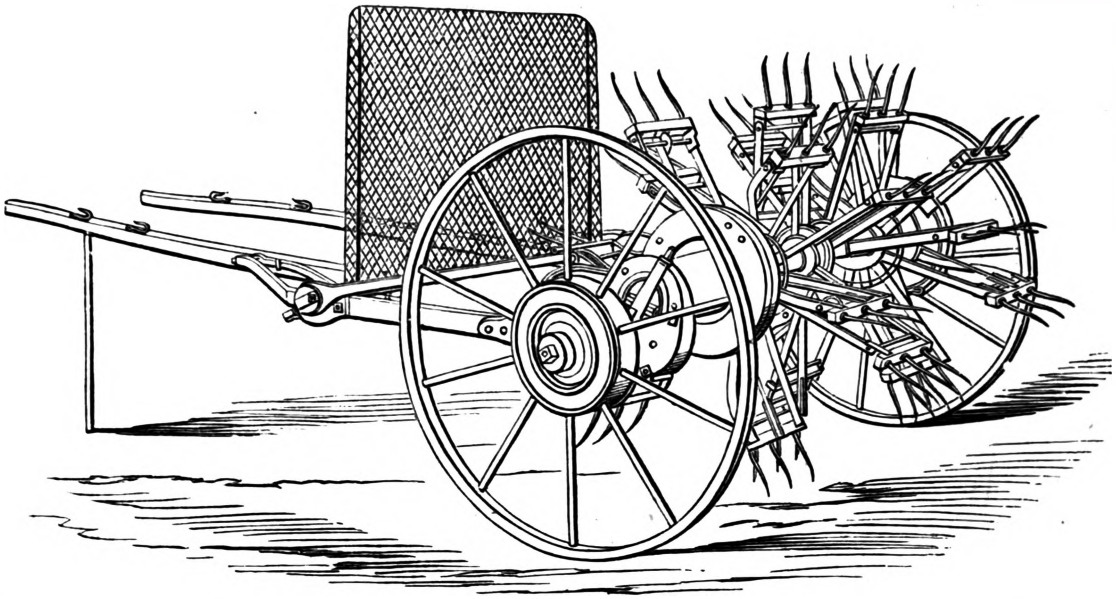
35.



*Howard's Double-action Haymaker*, for a single horse, is shown in Fig. 36. The axle in this machine is made of solid steel; this axle being strong is not liable to bend. The lines are well

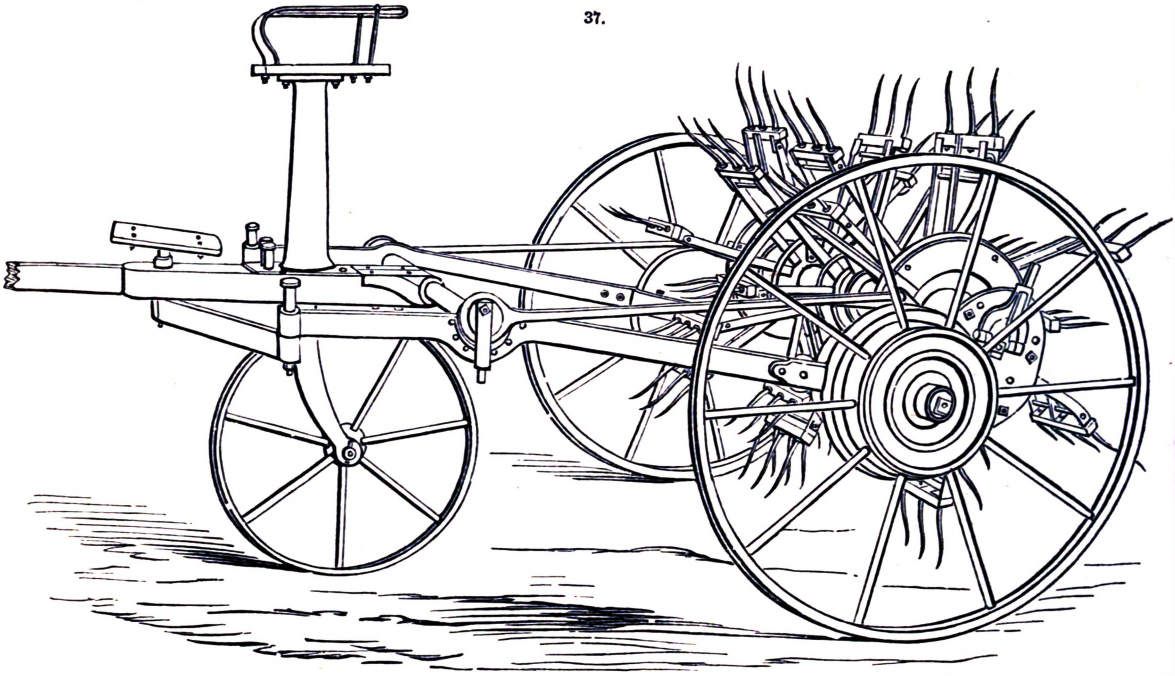
formed, and the forward action of this implement or machine effects a complete separation of the grass, while its back-action leaves the crop light and loose. The fork barrels are so arranged as to render clogging almost impossible; the forks are mounted in sets of three, and placed in a *zig-zag* position; this arrangement equalizes the work, while it separates and distributes the

36.



crop. The machine shown in Fig. 36 is fitted with a wire screen to prevent the grass from lodging on the front. The usual method of reversing the motion of such machines has hitherto been, either by loose sliding pinions operated by means of clutches on the fork barrels, or by sliding the fork barrels themselves; this last plan having the disadvantage of altering the relative positions of the forks, and rendering the machine liable to clog. In Howard's haymaker, the gear-work is strong and simple, and the motion can be changed in an instant to the backward or forward action by a simple eccentric movement of the main axle, and thus the disadvantages above pointed out are obviated. A similar eccentric movement is employed to raise or lower the fork barrels, so

37.



as to adapt the machine to the nature of the crop. When the forks are set for the forward action, no change is required when the backward action of the machine has to be brought into play.

Fig. 37 represents *Howard's Double-action Haymaker, designed for two horses:* the wire screen to

prevent the grass from lodging in front may be applied to this machine in a similar manner to that shown in Fig. 36.

To prepare the machine for work, take off the travelling wheels, grease the axles, see that the gearing is clean, and supply a little of the *best* machine oil to the two oil holes in each fork barrel and in each side plate. When the machine is in work, the axles must be greased and the gearing cleaned once a-day, and the fork barrels and side plates oiled two or three times a-day.

For the first tedding or breaking the swarthe, the forward action should be used. To put the machine into gear, move the lever opposite to the letters "F A" on the side plate. It is generally better to work the machine *across* the swarthe, as it spreads the grass more evenly.

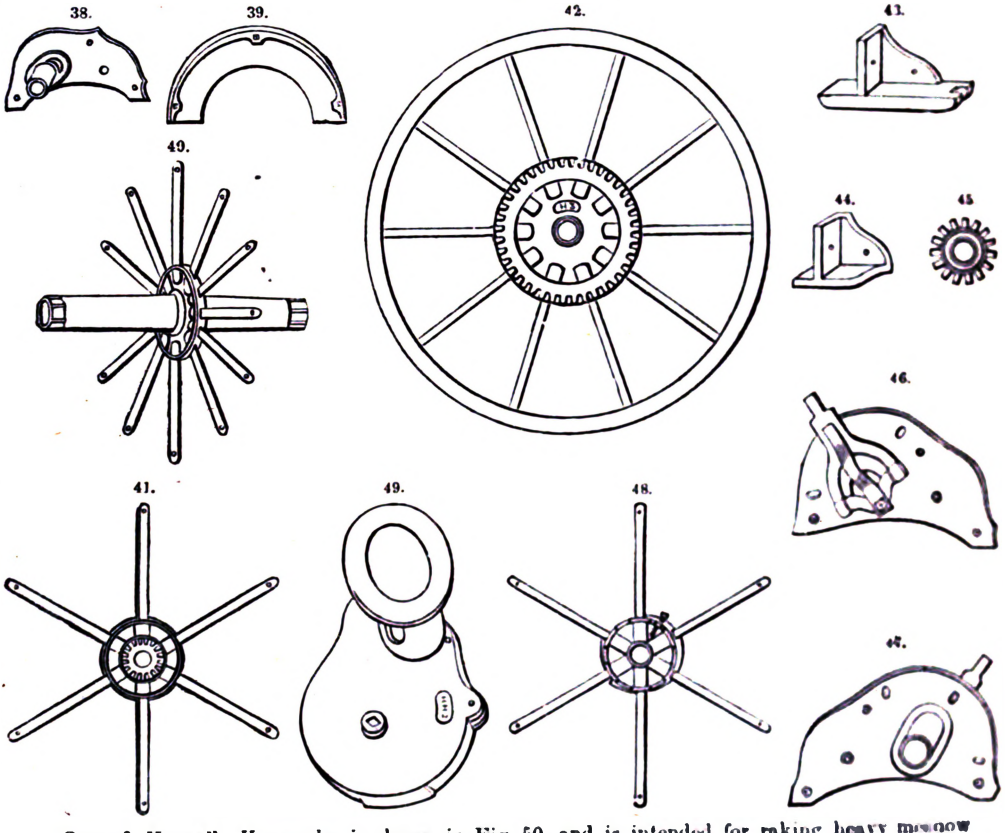
The backward action is to be used when the grass is partially dried, to lighten it up, and thoroughly expose it to the action of the sun and air. The backward action may also be used with great advantage for opening windrows.

The machine should be raised from and lowered to the ground to suit the state of the crop; the heavier the crop is, the higher the fork barrels should be. To alter the height of the machine, move the lever fixed to the end of the shaft bar. When working with the backward action only, set the machine near to the ground.

When the single haymaker is operated with, the best method of raising or lowering the fork barrels is as follows:—Close the fork-heads, raise the shafts gently till the heads rest on the ground, and then slacken the handle-nuts until the bolts can be raised or lowered into the required notch.

Should any of the parts of the machinery shown in Figs. 38 to 49 be accidentally broken, or require to be removed, they can be supplied separately and detached.

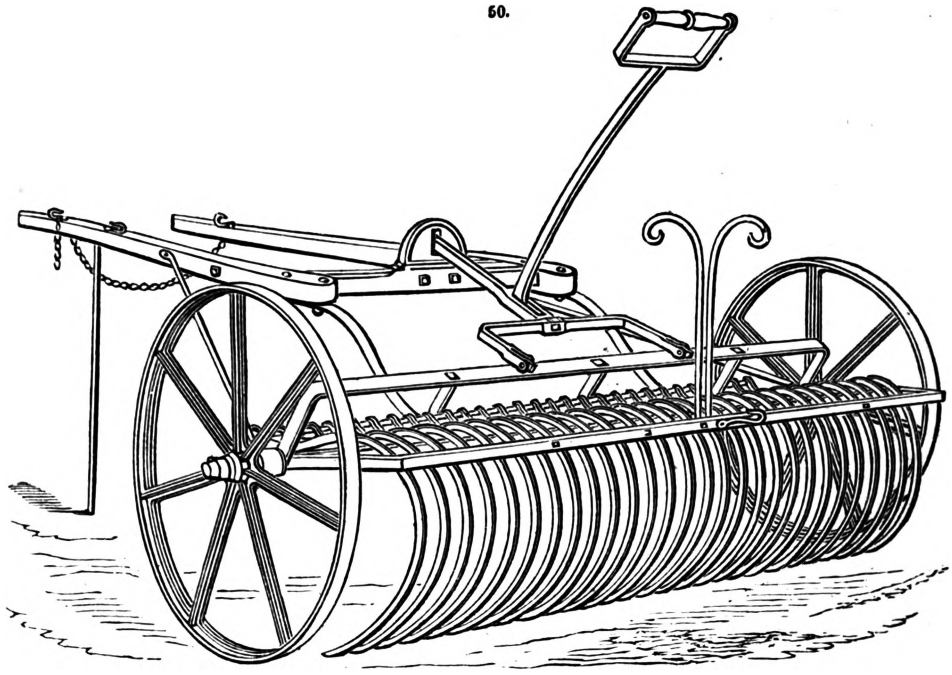
Fig. 38 shows the off side eccentric; Fig. 39, the covering plate; Fig. 40, centre star and barrel; Fig. 41, side star with pinion; Fig. 42, wheel; Fig. 43, fork head casting for spring; Fig. 44, fork head casting; Fig. 45, loose pinion; Fig. 46, near side eccentric (outside); Fig. 47, near side eccentric (inside); Fig. 48, side star; Fig. 49, wheel box.



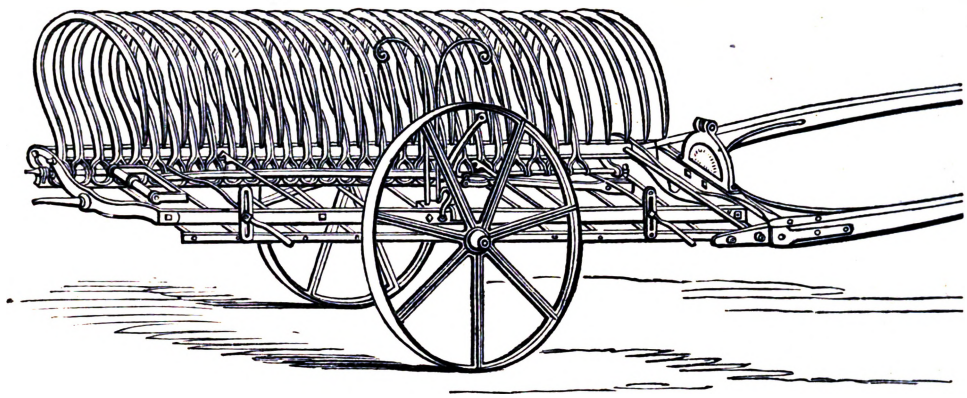

One of *Howard's Horse-rakes* is shown in Fig. 50, and is intended for raking heavy meadow crops, and for windrowing. Although this rake is of a large size, it is within the power of one man, and may therefore be used for general purposes. It can be fitted with a pole instead of shafts, and it has been found to leave the hay and corn in a looser or less compressed state than rakes of smaller size. These rakes have from 24 to 28 steel teeth each, the wheels are 42 inches high, the extreme width between the wheels from 7½ to 8½ ft.; the heaviest of these rakes does not weigh more than 5 cwt.

Fig. 51 shows a horse-rake on the same principle, but made so that the shafts can be readily removed to the end of the rake, by which means the implement can be drawn endwise through gateways or along narrow roads. This form of hay rake is well suited to mountainous districts where roads are narrow.

60.



51.



*On the Application of Steam-Power to Cultivation.*—This article is taken from a paper published in the 'Proceedings of the Institute of Mechanical Engineers, 1865-6,' the joint production of John Fowler and David Greig, of Leeds. In considering the mechanical problem to be solved in the application of steam-power to agriculture, it is requisite before referring to the design of any particular machine to examine the general principles on which the application of mechanical power to cultivation can be best effected. To do this effectually, it is necessary to ascertain the nature and extent of the difficulties to be overcome, and these may be stated to be the following:—

I. The irregularities of level in the surface to be acted upon.

II. The varying positions of the machinery upon the ground rendered necessary as the work proceeds.

III. The difficulty of getting heavy engines of sufficient strength moved about where no roads exist.

IV. The production of a rope of sufficient strength, hardness, and elasticity, to stand the work.

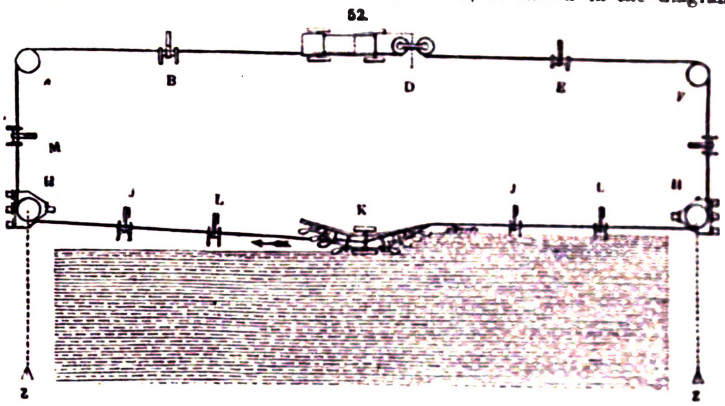
V. The changes in the state of the soil from effects of the weather.

I. The first idea which naturally occurs in applying steam-power is that of attaching the motive power direct to the implement, as is done in the case of horses. But experience has proved that the power required to move a steam-engine over land, of sufficient power and weight for traction purposes, is quite impracticable, from the fact that such an engine would weigh at least 12 tons, and would in many cases absorb as much as 30-horse power in the mere act of moving itself at the rate of 2½ miles an hour. Moreover, when the land gets at all wet and greasy on the top, it becomes quite impossible to make such an engine travel over the soil; while, moreover, the compression caused by its travelling over the land would in most cases neutralize the good otherwise effected by the cultivating implement. Under these circumstances it becomes

absolutely necessary to convey the power over the surface of the land by means of a rope, allowing the prime mover.

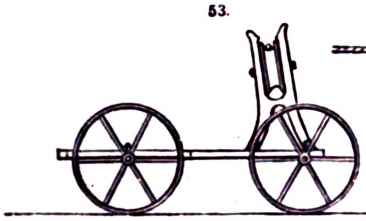
The use of wire rope for this purpose met at first with great difficulty, and was, from various causes, attended with great drawbacks, but these having been gradually overcome, it is now pretty generally applied. The first system of using rope was by placing the engine in a stationary position at the side or corner of the field to be cultivated, as shown in the diagram, Fig. 52,

52.




leading the rope all round the margin of the field: the two ends of the rope were attached to two winding drums at the engine, giving out and taking in the rope alternately, and the plough or cultivating implement being attached to the middle of the rope, was hauled backwards and forwards across the field. This rectangular arrangement involved a great deal of fixing machinery in the field before commencing operations, including fixing the engine and windlass, fixing a pulley or snatchblock at each of the two corners of the field nearest to the engine, and a large number of rope porters, or carrying pulleys; it also entailed two movable anchors, one at each end of the line of traverse of the implement, which had to be shifted by some means each time that the traverse was reversed, so as to lead the implement into a fresh line. In Fig. 52, D is the engine, B E J L M are rope porters, C the windlass, A and F pulleys, H H movable anchors, K the plough, and Z Z stationary points. The general construction of the rope porters is shown in Figs. 53, 54, 55, 56, 57, 58. Figs. 53, 54, 55, show the larger kind used for the permanent lines

53.



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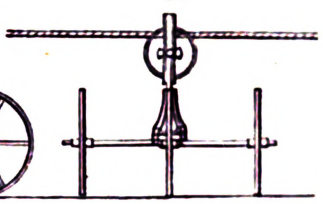

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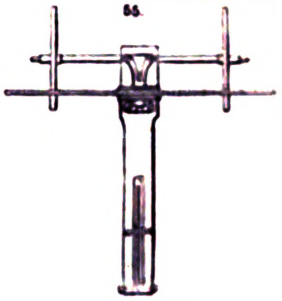

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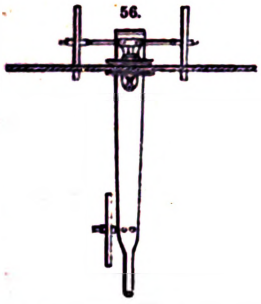

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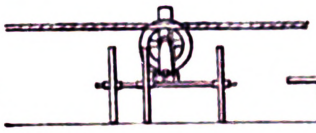

58.

of rope, and Figs. 56, 57, 58, show the small porters for the rope attached to the implement, which are withdrawn and placed again by boys as the implement passes across the field. In employing such an arrangement of tackle, the consideration of the complication of the parts, the numerous pulleys and frequent bending of the rope over the pulleys, which were of necessity small in diameter, and the great time required for fixing the apparatus, early led to the conclusion that such plan of applying power could not prove permanently successful, and so it is now superseded by more direct and simple arrangements.

The second mode of using wire-rope, shown in Fig. 59, was merely a modification of the first, and consisted in placing the stationary engine and windlass in the centre of one side of the field, and leading the ropes away diagonally across the field to two movable anchors placed at each end of the line of traverse of the implement. A pair of horizontal leading pulleys attached to the windlass allowed the rope to pass off at the varying angles which the progress of the work required until both the movable anchors came in a straight line with the windlass. By this triangular plan the two fixed pulleys in the corner of the field, in Fig. 52, were dispensed with

and fully one-fourth of the rope with its requisite porters was saved. This arrangement was a great improvement on the former, and the encouragement that it elicited led to a further step,

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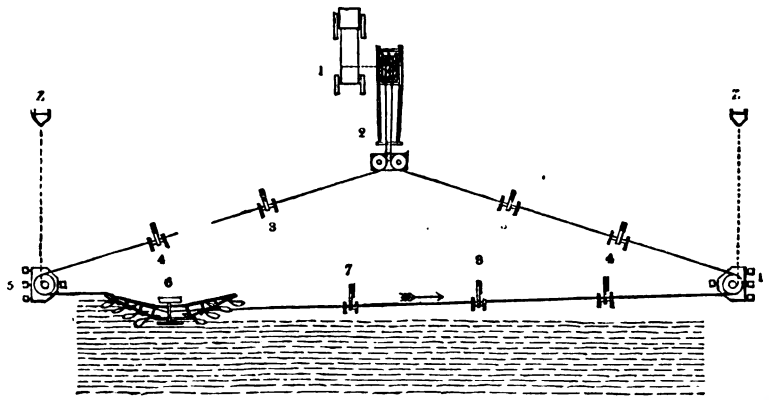


which suggested the important principle on which all subsequent machines have been constructed, namely, that of direct pull.

In Fig. 59, 1 is the engine; 2 the windlass; 3, 4, 7, 8, rope porters; 5, 10 movable anchors; 6 the plough, and Z, Z, stationary points.

The third plan of working with rope, with direct pull upon the implement, is shown in Fig. 60, and consisted in placing two horizontal winding drums under a travelling engine which moved

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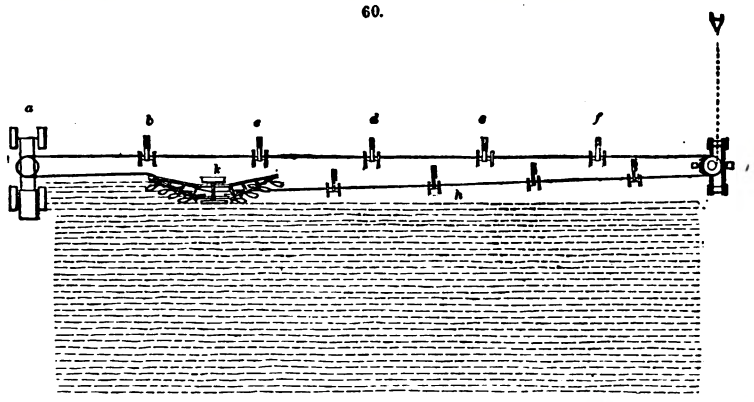


slowly along the headland of the field, keeping always in line with the work. The travelling motion was obtained by means of a pinion gearing into a large internal toothed wheel fixed upon one of the carrying wheels of the engine, and connected to it by a friction clip to prevent any risk of injury from overstrain. The rope was stretched from one winding drum of the engine across the field to a movable anchor on the opposite headland, and then back to the implement to which it was attached, and another rope from the other drum was also attached to the implement. The work was performed by the engine winding up one drum as it gave off rope from the other, the implement being thereby pulled backwards and forwards across the field.

In Fig. 60, *a* is the engine, *b c d e f h* rope porters, *g* the movable anchor, *k* the plough, and Z stationary point.

The movable anchor is shown in Figs. 61, 62, and consists of a carriage with a horizontal pulley, A, mounted on it, round which the hauling rope, B, of the plough worked while the sharp-edged carrying wheels, C, entered the ground and resisted the side pull of the rope. The anchor carriage was moved forward each time of changing the direction of the implement by means of a stationary rope, D, stretched along the headland and made fast at the end, as shown in Fig. 60. This rope was attached to a small drum, E, on the anchor carriage, and a slow motion was communicated to the drum from the pulley, A, by the two pair of wheels and pinions, F, being thrown into gear, the anchor carriage thus pulled itself along the headland a sufficient distance each time, so as always to keep in line with the implement and engine. The box, G, on the carriage was weighted sufficiently to serve as a counterpoise to the pull.

The experience gained in this plan of working showed that the principle of direct pull of the engine upon the implement was the correct one, but the cumbersome arrangement of the two winding drums and the difficulty of coiling the whole length of rope required for reaching across the field, together with the crushing of the rope arising from the soft material of which it was then made, and the small diameter of the drums necessarily employed, indicated the need for a still further modification in the apparatus. The next step was the employment of an endless rope stretched across the field, as in the preceding case, with this difference, that the power was now communicated to the rope by friction instead of by winding on and off a drum, as in the plan last

described. In order to secure such an amount of hold on the rope as to give sufficient pull, it was found necessary to employ two driving drums with four grooves each, as shown at A A in

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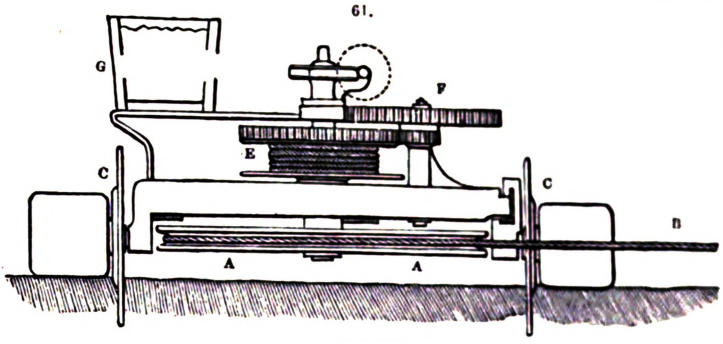
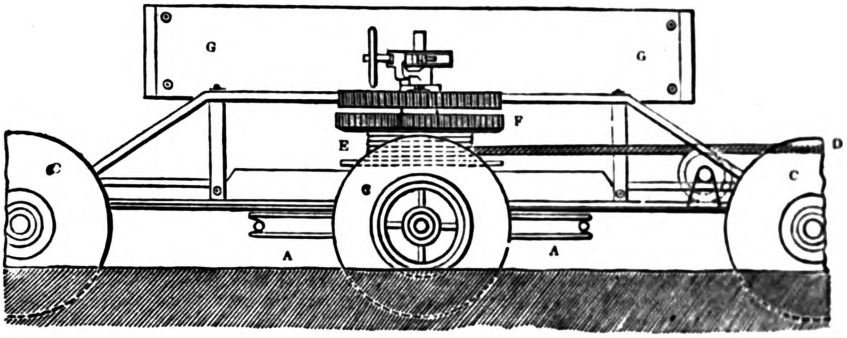



62.




Figs. 63, 64; and the rope was led four times half round both drums, as in Fig. 64, the two drums being geared together by the pinion B. By this means sufficient hold was obtained to

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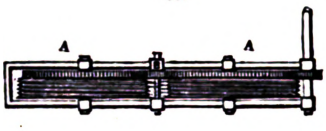
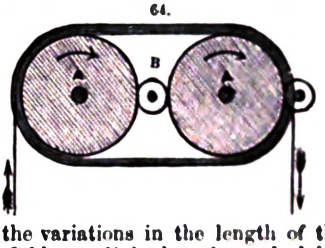



64.

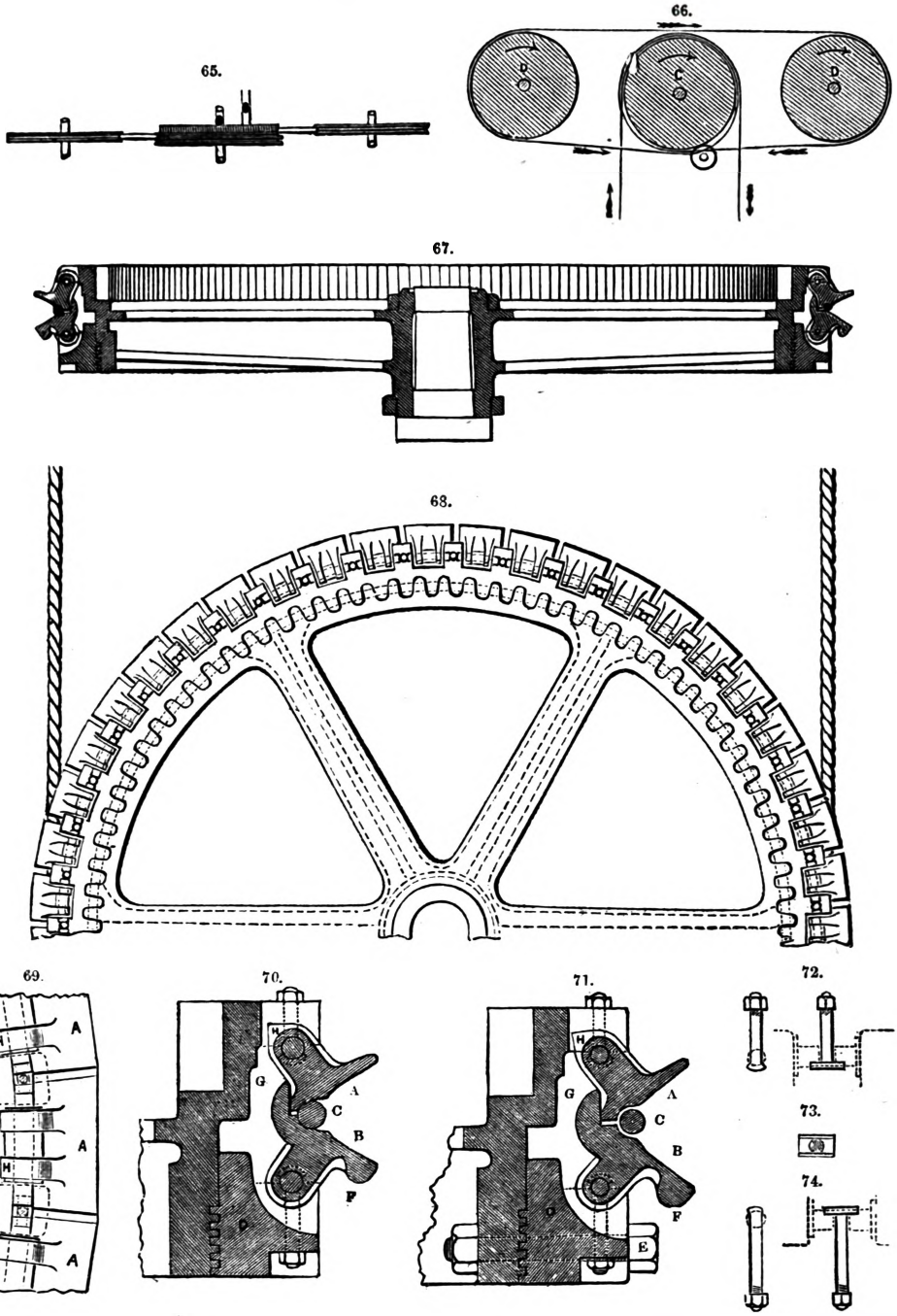



overcome the resistance of the work. In order to meet the variations in the length of the rope occasioned by the irregularities in the boundary of the field, two light barrels worked by hand were mounted on the cultivating implement to which both ends of the rope were attached, and by these barrels a portion of rope was let out or taken up by hand as required to keep it at the proper degree of tightness. When new, this apparatus worked very well, but the wear and tear of rope from its numerous bends, and more especially from another cause, which required some time to develop itself, rendered it necessary to abandon this plan. This great difficulty was the impossibility of keeping the eight grooves of the driving drum all of equal diameter. The two leading grooves were found to be always wearing at double the rate of the others, and all the grooves having to revolve at the same rate, a constant surging of the rope was occasioned by the difference in speed of the circumference of the different grooves. This involved destructive wear of the rope and loss from friction, and every revolution of the drums caused a further grinding away, thus increasing the errors in the diameters of the grooves. As an instance of the deterioration thus occasioned, it may be mentioned that the apparatus got into so bad a condition that the engine could not perform one-half the work that was done by it when new.

These evils led to a modification of this plan of driving, by the employment of a single driving drum with two V-grooves, as shown at C, Figs. 65, 66, round which the rope was made to take two three-quarter turns, one in each groove. This was effected by using two guide pulleys, D D, one on each side of the driving drum C, which transferred the rope from one groove to the other of the driving drum. In this case, as there was only one driving drum with two grooves in it instead of two drums with four grooves in each drum, the wear and tear were greatly diminished; and this plan of apparatus, although retaining to some extent the evils of the former, is still working successfully in several places. The objections still remaining, however, are the number of bends to which the rope is subjected; and from the grip on the rope being obtained by its forcing itself into the V-groove by the tension put upon it, serious wear and tear result. In this case there is a compound surging, for from the point where the rope first touches the drum, the pressure, forcing the rope into the groove, increases as the rope passes round the drum, causing the rope to lie deeper in the groove, whereby it virtually lessens the diameter of the

drum, in consequence of which the rope must keep on surging endways at the same time that it sinks deeper into the groove. Although these movements are so small as to be imperceptible to the eye, they are actually taking place continually, and the result is serious wear and tear from the continuous grinding motion over the whole rope in succession.

The clip drum is shown in Figs. 67, 68, 69, 70, 71, 72, 73, 74.




The application of the clip drum has been found to economize the motive power, and to facilitate the required movement.

The clip drum consists of a series of jaws or clips, A and B, hinged round the circumference of the drum close together in a continuous line, forming a complete groove, in which the rope C works. Each pair of clips in succession, as it passes round to the point where the pressure of the rope upon the drum commences, closes and seizes hold of the rope, as shown in Fig. 70, and continues to grip the rope throughout the half revolution, until reaching the point where the rope begins to leave the drum, when the clips fall open, as shown in Fig. 71, being relieved from the

pressure of the rope. The amount of grip is in all cases proportionate to the pull upon the rope, and such as effectually to prevent any slipping.

The only provision requisite to suit the clip drum for working with any size of rope is to adjust the width of opening of the clips to the particular diameter of rope to be driven, by widening or contracting the distance between the centres of motion of each row of clips. This adjustment is effected in a very simple and complete manner, by having the lower row of clips, B, centred upon a ring D, Figs. 70, 71, which forms the circumference of one-half the depth of the drum, and this ring is screwed upon the body of the drum by a thread chased round its entire circumference, so that by turning the ring round in either direction the distance between the centres of the upper and lower clips is simultaneously increased or diminished in every pair to exactly the same extent, all of them being kept in perfectly parallel positions. The ring D is held in the desired position by the bolt E, Fig. 71, which prevents it from turning.

The lower clip, B, of each pair having a heavy overhanging lip, F, on the outside, is enabled to lift the upper clip, A, by means of a small finger, G, projecting from its inner end, and pressing upon the tail of the upper clip, so that the clips always remain open until receiving the pressure of the rope, and they fall open again, and release the rope the moment the pressure is withdrawn. The stop H on the upper clip, coming in contact with the body of the drum, prevents the clips from falling open too far. Figs. 72, 73, 74, show the bolts that serve as keeps for holding the ends of the pins on which the clips are centred.

The action of the clips is similar to the closing of a hand upon the rope, laying hold at once so firmly that the rope cannot slip, and retaining this hold uniformly until the rope is released altogether by the opening of the clips, so that all friction or surging from an imperfect hold is avoided, as well as any shifting of the rope at the beginning and end of its contact with the drum, such as is inevitably the case in round or V-shaped grooves; at the same time, by means of the ring D, on which the lower row of clips are centred, the hold upon the rope can be adjusted to any desired amount, according to the power required to be transmitted, and it can be absolutely depended upon when once adjusted to continue working uniformly with the same amount of hold.

An important practical advantage found to result from the working of this clip drum is that the rope is subjected to a continual pressure upon its sides whilst passing round the driving drum, thus avoiding all tendency to the rope of being flattened by the pull, as in an ordinary round bottomed groove, where the pressure of the rope is upon the bottom of the groove only. Also the groove in the clips being so curved as to fit the rope closely round a considerable portion of its circumference, the pressure preserves the form of the rope, and serves to consolidate it by continually closing down all protruding wires, and preventing the deterioration of the rope by such parts being caught in passing the subsequent guide pulleys. In the working of this apparatus, it will be seen, from Fig. 60, that one-half of the total length of rope is never in contact with the driving drum, the other half alone being passed round it backwards and forwards successively, and, in many cases, the actual result has been that the portion of the rope which passes round the drum, and has all the work to do of transmitting the hauling power, has lasted longer than the other portion which has no such work to do, but is simply exposed to the bend round the pulley of the movable anchor on the opposite headland, the friction from the guide pulleys being exactly the same in both cases. Another important advantage is that no tension is required upon the rope leaving the drum; all that is requisite is that the rope be taken away, and not allowed to kink.

It may be remarked that these advantages of the clip drum render it specially adapted for use in other positions where a rope is the medium of conveying power, and the saving that it has effected in the wear and tear of the rope employed in cultivation has been fully corroborated by the result obtained in its use for other purposes.

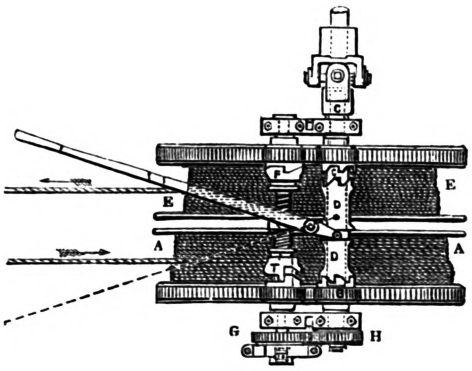
The second point of difficulty for consideration is the continually varying positions of the machinery upon the ground rendered necessary as the work proceeds, in consequence of which it is necessary for some means to be provided whereby the ropes will admit of the two extreme points being moved nearer together or farther apart, as the varying boundary of the fields may require. With a pair of winding drums this is easily effected, by not allowing the unwinding drum to begin by giving off rope until the rope becomes tight in each case. For this purpose a heavy break has to be applied to the paying-out drum to save the rope from trailing on the ground, for if the rope is not kept from touching the ground a serious loss of power is the result, as the difference in draught required to pull a rope lying on the ground and one properly carried is as much as ten to one. Hence it becomes a very important point that the rope should be efficiently carried off the ground.

Figs. 75, 76, show the construction of the compensating break that is employed when a pair of winding drums are used, so as to compensate for changes in the length of rope that is required as the work proceeds. The winding drum A is driven by the pinion B, which is coupled to the driving shaft C by the clutch D, but the driving shaft is geared to the paying-out drum E by means of the second shaft, F, having corresponding pinions at each end, so as to allow the two drums to run in opposite directions. The two pinion shafts, C and F, are however made to revolve at slightly different speeds by the two outside pinions, G and H, that gear together, being of different size, the pinion H being one-ninth smaller than the other, and consequently the paying-out drum E is compelled to revolve one-ninth slower than the winding-drum A. This causes the slack in the rope to be all taken up by a few revolutions of the drums, and further strain on the rope prevented by the pinion G being connected to its shaft by a friction-break, I, so that it is allowed to slip on the shaft. The rope is thus kept constantly stretched tight by the friction of the break T.

When the endless rope and clip drum are employed for working the implement instead of two winding drums, a very ingenious and efficient plan is adopted, whereby the rope is kept tight without any loss of power, the slack of rope is taken up or more rope is given off, as the field may

require, and the implement cannot be started until the rope be tight. This is effected by means of what is termed the slack gear, which is shown in Figs. 77, 78, 79, 80. It consists of two small barrels, A and B, mounted on the plough and connected by gearing with a relative speed

75.

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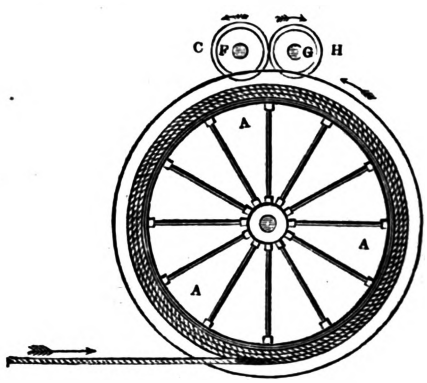
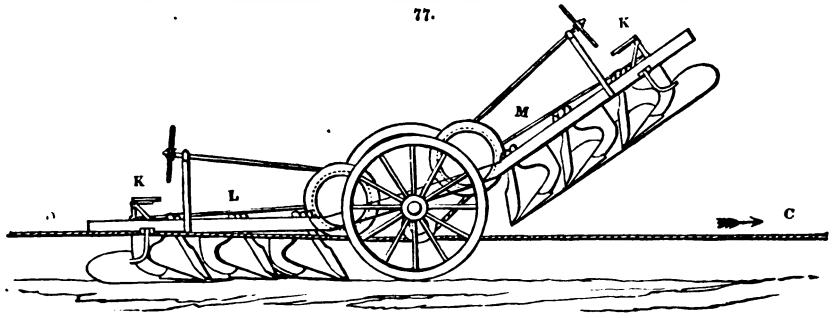



of five to one, so that the pulling rope C, in drawing off one foot length of rope from the barrel A, winds up 5 ft. of the slack rope D on the other barrel B, until all the slack is taken up. The implement then starts at once, when the rope becomes tight, and on its arrival at the other end of the field the act of the man taking his seat at the other end of the implement reverses the action of the barrels, so that what was the slack rope barrel B, becomes the pulling one, and *vice versâ*. The driving of the barrels A and B is effected by a pitch-chain E, which passes over a wheel F,

77.

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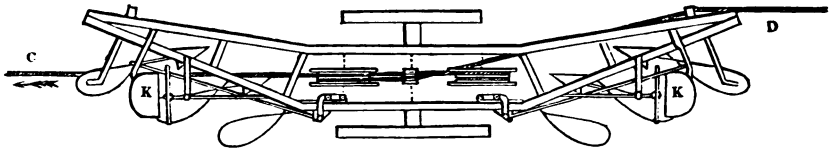


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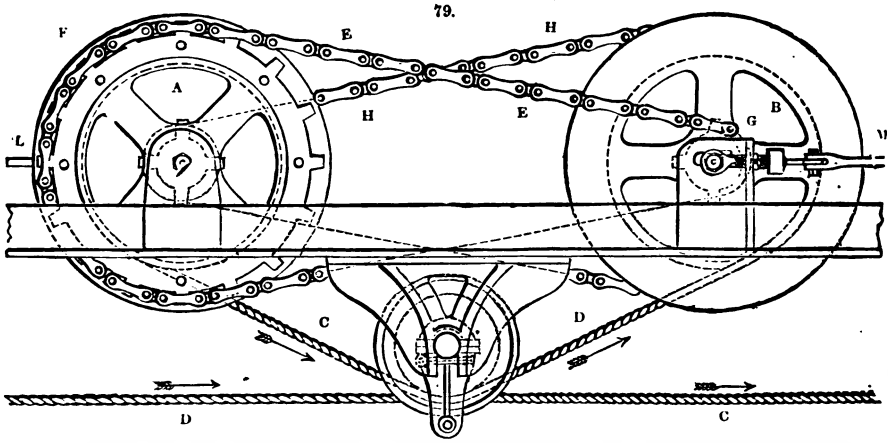
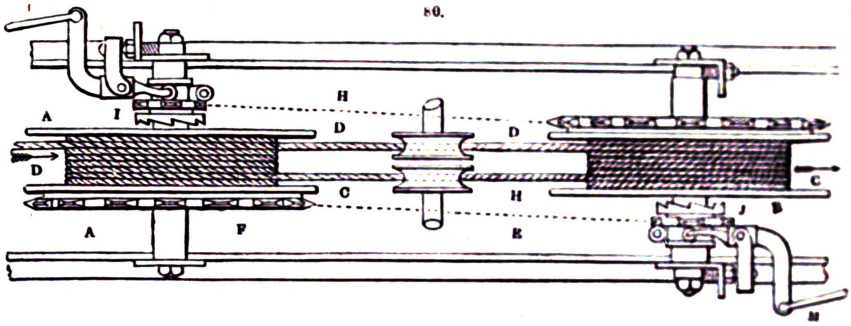



of large diameter, on the pulling-barrel A, and over another, G, of one-fifth the diameter on the slack barrel B, a second chain H being placed on the opposite side of the barrels, working over a pair of wheels of corresponding sizes to the former, but reversed in their relative positions. The

self-acting levers and clutches, L and M, are both kept in gear by springs, but are thrown out of gear alternately by the act of the man taking his seat upon the seat K, Figs. 77, 78, first at one end and then at the opposite end of the plough, and by that means pulling the rod L or M. The same action is thus obtained in whichever direction the implement is travelling, one of the chains E or H with its pair of driving wheels being always kept in gear with the rope barrels whilst the other is out of gear. An advantage arising from the use of the slack gear is the elasticity thereby afforded to the rope, should the progress of the implement be obstructed by its coming in contact with stones or roots in the ground: in this case, the rope not being absolutely tight, has a margin for taking up further slack, which acts as a spring easing the strain caused by stopping the implement suddenly. The third difficulty to be considered is that of getting heavy engines of sufficient strength to be moved about over the ground where no roads exist.

80.




This has been a serious drawback to the introduction of steam cultivation, and one which has led to more breakage of tackle and machinery than all the action of the machinery in performing its work of cultivation. Two causes have contributed to this result, namely, a mistaken idea at first prevailing, that lightness was an essential point, which led to paring down the metal in all parts of the machinery, instead of making the machinery so strong that it could not be broken by the full steam-power, and then increasing the width of the carrying-wheels to such an extent as to ensure carrying the engine over the heaviest and wettest fields. The other mistake was that the speed of working on the road-wheel was not reduced sufficiently so as to allow the engine sufficient leverage to get out of any difficulty it might happen to get into; and the want of judgment on the part of the men using these machines, often led to their being put in places of unnecessary difficulty. The first of these mistakes has been met by making the machinery so strong that the steam when full on is the weakest part of the whole machine. This has naturally led to great weight, but that is no real obstacle, provided the carrying power of the wheels is increased in proportion to the increase of the weight to be carried. In fact, the weight is an advantage in steadiness for working, so long as the machine can be kept from sinking too much into the ground.

Carrying-wheels are now being made for special purposes as much as 30 inches wide on the rim, as shown in Figs. 81, 82, where the dotted lines A A show the portion that is added to

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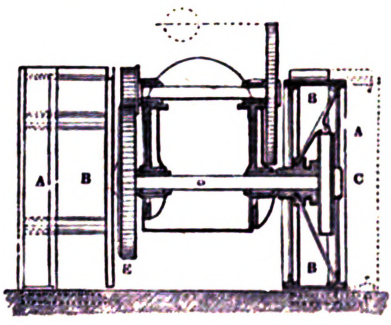


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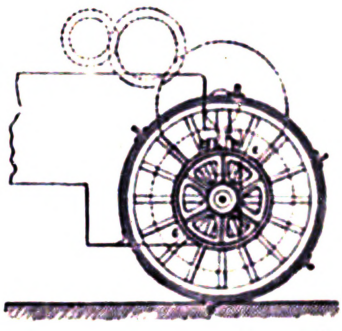
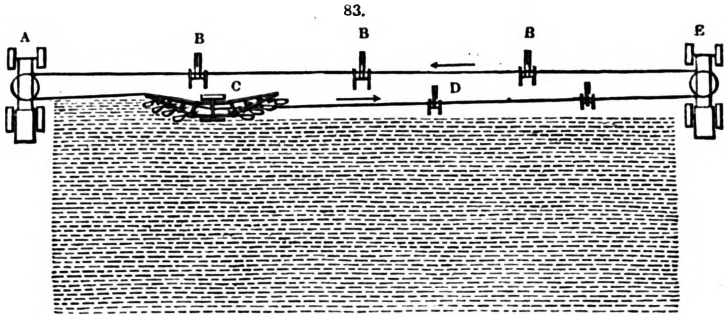


the ordinary 20-inch wheels B B, and these wheels have been proved to carry a 12-ton engine over any land in a fit state of cultivation. The wheels are driven, each separately, by means of a friction-clip C, which prevents any risk of breakage from excessive strain of driving, the shaft D being driven by the pinion and spur-wheel E.

The next point was to reduce the speed on the driving-wheel, so as to give the engine sufficient leverage to get out of any difficulty; and for this purpose two different driving speeds are provided, one giving 2½ miles per hour and the other only 1 mile per hour for travelling, when the engine is working at its full speed of 140 revolutions per minute. In order to obtain sufficient adhesion under specially difficult circumstances for the exertion of the full tractive power of the engine, the additional provision has been made of temporarily fixing transverse T irons by means of bolts upon the rims of the wheels, as shown in Figs. 81 and 82. With regard to the men, time and experience, combined with the extra work caused to them by getting into difficulties, are the means of gradually reducing the difficulty arising from want of judgment on their part

Another plan for meeting the difficulty of getting such heavy machines moved about has been adopted with the most satisfactory results. This consists in combining the power of two small-sized engines, as shown in Fig. 83, the second engine being worked in place of the movable anchor

83.




in the previous plan of working shown in Fig. 60. Each engine is provided with a clip-drum, which is essential to carrying out this system of cultivation; and the rope is worked as an endless rope between the two engines by having both its ends attached to the cultivating implement. As the power of both engines is applied at the same time to the rope in each direction, the heaviest class of operations can be performed by them; and the loss of power in working the rope is very much lessened by the fact that both lines of rope are always in effective tension, and are thereby well carried with half the number of rope porters. Another advantage derived from the adoption of this plan is that the engines are better adapted for the other work of the farm, as the farmer has then two engines of 7 or 8 horse-power instead of one engine of 10 or 14 horse-power; and by having two of them a regular system of cartage on the farm can be carried on, the engines being specially arranged for traction purposes.

In Fig. 83, A, E, are the engines; B, B, B, D, rope porters; and C, the plough.

The fourth difficulty to be surmounted was the production of a rope of sufficient strength and hardness, combined with elasticity, to stand the required work; and this was a very serious point, as the inability to accomplish it nearly upset at one time the profitable employment of steam cultivation.

The first rope used was made of iron wire; but it was worn out so quickly, not doing so much as 200 acres, that it soon became evident such material would not stand the strain and friction attending the work; whilst by increasing the strength of the rope its weight was so much increased as to consume nearly the whole engine-power in overcoming its friction. These difficulties became so serious, that great exertions were made to get a rope of steel sufficiently hard to stand the wear of trailing on the ground and also the friction caused by coming in contact with the numerous pulleys of the machinery then employed; and in 1857 two steel ropes were applied which answered the purpose admirably, and performed with the then imperfect machinery upwards of three times the amount of work that was done by the first iron rope. From this point it was established undoubtedly that all risk of the difficulty with the rope causing a check to the application of steam to cultivation was now safely overcome, the introduction of the steel rope having effectually accomplished the object in view. The machinery for working the rope, however, required great improvement and alteration before getting to the point of thorough efficiency with a minimum of wear: the chief objects in these improvements being to have as few bends as possible, and those bends over large pulleys. A great saving in the wear of rope has also been effected by the improved means of keeping the rope tight, preventing it from dragging upon the ground. From time to time, as the various improvements in the machinery have been effected, the increased quantity of work done by the rope before being worn out has been very marked; so that the cultivation of from 2000 to 4000 acres can now be accomplished with one steel rope, the amount varying with the nature of the soil and the width of the implement used.

Although much of this increase of duty depends upon the construction of the machinery, still a great part of the success is to be attributed to the superior manufacture of the steel wire. At first the steel ropes, although much superior to those of iron wire, were very irregular in their quality and durability, often varying as much as one-half in these respects; and up to the present day steel ropes made of the common qualities of steel wire vary in their quality to the same extent. After a series of careful experiments, combined with accurate testing, a quality of wire has now been produced for the purpose, which can be obtained of complete uniformity in tensile strength, and possessing a high degree of hardness, combined with the requisite flexibility and toughness for working. To this great advance in the manufacture of steel wire rope is to be attributed in a great measure the present success of steam cultivation. The tensile strength of this wire has been increased from 1500 lbs. to in some cases 2400 lbs. for No. 14 wire gauge. Steel wire of the common sort has indeed been made to attain nearly the same tensile strength; but this is always accompanied by the defect of brittleness, which is a fatal defect in the working of a wire rope. If the quality of steel rope should continue to improve at the same rate as during the last three years, the cost of wire rope will be reduced to an unimportant item by the acre.

At the commencement of steam cultivation the iron wire rope ran a mileage of not over 750 miles before being worn out, costing 1*s.* 7*d.* the mile of running. The first steel rope ran 1800 miles, costing 1*s.* a-mile; and the present steel ropes are running on an average 9000 miles, costing only about 2¼*d.* a-mile, running with a tension upon them of about 25 cwt., and this notwithstanding that the price of rope has been increased from 60*l.* to 84*l.* for the ordinary length of rope

of 800 yards. The steel rope at present used in steam cultivation is $\frac{11}{16}$ths inch diameter, and weighs about 2 lbs. a-yard, making a total of about 14 cwt. for the length of 800 yards.

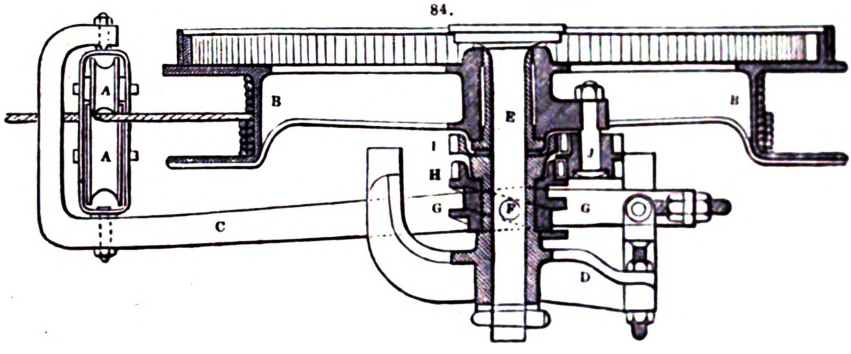
The fifth class of difficulties are those arising from variations in the state of the soil caused by the effects of the weather.

These difficulties have been principally felt in wet weather, in moving the engine, and also from the stickiness of some land when in a half-wet state, which is too often the condition of the land whilst being cultivated. In such cases all the tackle would become literally covered with clay, and the power required to move the rope and the machine would be very great. This difficulty should not indeed exist, as no land ought to be touched when in such a state; but clay land has hitherto been very often worked when wet, from want of sufficient force to get all the work done before the wet sets in, and also from the inability of horses to perform the work while the land is in a dry state. As an illustration may be taken a clay-land field ploughed by horses while very wet, after which, if the next year be dry, it will be literally impossible to work the same ground with horses until some rain comes to soften it, as the horses' shoulders and the implement would not be able to stand such jarring work.

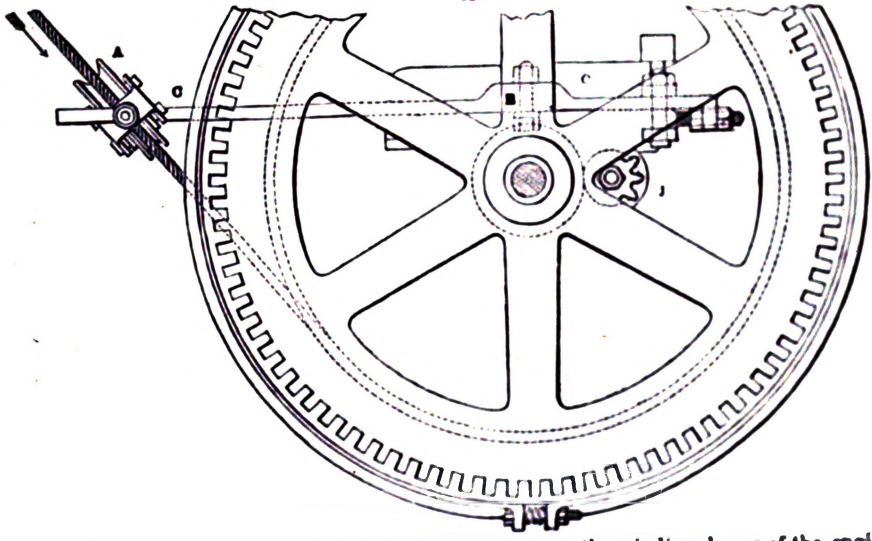
With steam-power, however, there is no difficulty in working the land in the driest condition, which is the proper time for such work; and if this is strictly attended to, it will never get into an extremely hard state. Supposing the clay land is ploughed wet by steam-power, more power will be expended in pulling the dirty rope and the sinking plough than even if the land be so dry that the soil breaks up into large pieces of as much as 1 cwt. each, though the latter could not be the case but for the wet-kneading that the land received before by being ploughed wet by horses. If the farmer were only to keep his machine off the land in wet weather, and work it night and day in dry weather, he would see the great advantage that would accrue from working at the proper time. In fact, the principle of the old maxim, "Make hay while the sun shines," applies to cultivation of the land as well as to the making of hay.

Another system of steam cultivation, shown in Fig. 83, has been adopted to meet special circumstances, by the use of two large engines, each of which is supplied with a winding drum, instead of the clip drum and endless rope employed with the light engines in the plan last described. The two large engines are placed at opposite ends of the field, the same as in Fig. 83; but they act alternately instead of in combination, one pulling the plough in one direction, while the other moves forward into position for the return bout, and *vice versâ*.

84.




85.




In order to make the rope coil in a regular manner upon the winding drums of the engines, an arrangement of self-acting coiling gear is employed, which is shown in Figs. 84, 85. It consists

of a pair of guide rollers A A, between which the rope passes when coiling on or off the large winding drum B. These guide rollers are carried at the end of an arm C, which is centred at the other end upon a bracket D carried loosely upon the centre spindle E, round which the drum revolves. The arm C has a stud fixed in it at F, working in a spiral groove G, formed on the lower part of the spur wheel H, which also turns loosely round the centre spindle E. A second spur wheel I is carried close above the wheel H, and is fixed upon the upper end of a cylindrical casing carried up from the bracket D, and passing through the wheel H. A pinion J carried by a stud fixed in the winding drum B gears into both the wheels H and I, but the upper wheel I has one more tooth than the lower one H; and consequently in each revolution of the winding drum the pinion J being also carried round with the drum causes the lower wheel H to be advanced one tooth, the upper wheel I being held stationary by the arm C, which is held at the outer end by the tight-stretched rope passing through the guide rollers A. The spiral groove G is thus gradually turned round, and acting upon the stud F in the arm C, causes this arm with its guide rollers A to be gradually raised and lowered, thereby guiding the rope from top to bottom of the drum in regular coils whilst it is being wound on or off the drum.

The purpose for which this system of working with two large engines was arranged was for travelling about and doing work by hire, so as to meet the requirements of those who have not sufficient land or capital to purchase machinery for their own use. The plan has the advantage of requiring no fixing, and the machines are ready to start work the moment they get into the field; and as soon as the implement stops, the ropes are in their places and the machines ready for removal. As fields of all shapes are met with, it is of importance that the machines should be of such a character that no loss of time should be occasioned by the management of the rope. So far as the working of these machines goes, it is entirely satisfactory, but the first drawback to the adoption of this plan is the price. Secondly, there is the difficulty of taking two large engines about; and from the fact that a heavy break has to be put on the paying-out drum in order to keep the rope tight, considerable power is lost. But still the time saved in doing small irregular fields more than counterbalances those disadvantages.

The traction part of the machinery having now been considered, the most mechanical means of performing steam cultivation has to be referred to.

The implements hitherto used for steam cultivation have been something similar to those employed with horse-power; but recently a system has been arranged for throwing up the land in the roughest possible way, and leaving it in such a state as to expose the largest amount of surface to be acted on by the air, which is the only truly practical way of dealing with heavy land. The development of different classes of implements will always be going on, to meet different varieties of land, and the various operations which will ultimately be required. It is proposed here only to refer to the best principle of loosening the land for the purposes of cultivation, looking at the question entirely from a mechanical point of view.

Cultivation by rotary implements has been much advocated, and may appear at the first glance the right means of applying steam-power; but when the nature of the substance to be dealt with is considered, this plan is mechanically wrong in the way of operating on the soil, from the fact that rotary implements must necessarily strike on the top of the hard land, thus absorbing a quantity of power in entering the hard substance. As an illustration of this, reference may be made to the method adopted in breaking up a macadamized road: the pick is used so as to lever the material upwards, and by entering it underneath the hard substance the latter is easily broken up. A rotary digger must however be used in the contrary way, or else it will be acting against the onward motion of the machine, thereby increasing the power required for traction. The difficulties that interfere with getting such a machine over the surface of the land have also to be considered, and the damage done to the land by the transit of such a heavy machine over the soil to be cultivated; and these objections, with the serious error in the mode of applying the power, must prevent such a system from proving practically successful.

The cultivation of the land consists merely in loosening a certain quantity of soil, and what has to be considered is how to loosen the greatest quantity with the smallest amount of power. In all the experiments tried by Fowler and Greig it has been found that this is never so economically done as by wedging the soil off to a loose side, and entering the wedge underneath, where the soil is softer. Much objection has been raised to the old mode of working with the plough; but it is not the implement that is at fault in that case, but the power that is defective; and by the aid of steam that implement can now be driven at such a pace as to throw the land sideways in a manner quite equal to the effect of any digging by hand. The great point requiring attention is that the tools should be so arranged that each follows its neighbour, taking its own cut and wedging off the soil to a loose side. If this is done, the speed of 2½ miles per hour at which the implement is driven will throw the loosened material at least 2 feet clear from its previous position, and by the rapid motion it will be left in the state most desirable to the farmer, and in the best possible condition to receive the action of the atmosphere, and this will be effected with the least amount of power. Few implements embody this principle; but without it there is a great loss of power, which is accounted for by the fact that a tyne or cutter, in making its way through the solid ground, always takes twice the power to draw it that would be required if it were taking its cut close to where another cut had been taken before. This is a point of great importance, and should never be lost sight of in the construction of implements for heavy work. In the implements for light operations it is by no means so necessary; but still the principle holds good to a certain extent, and should be attended to as far as practicable.

In order that steam cultivation may be brought to the greatest perfection, it is of the utmost importance that the use of horses in cultivation should be altogether abandoned. For this purpose a number of implements are required, adapted to get over a large breadth of land in a day, so as to do the very light operations of the farm and exclude horses entirely from such work, as their use inevitably increases the expense of after-operations, besides being detrimental to the land. If the

horses on a farm are done away with altogether, or as far as practicable, the cartage becomes the next question to be dealt with; and before steam cultivation takes its proper place, the heavy part of the cartage must be done by the ploughing-engines. Considering, however, that to be good ploughing-engines they must be good traction-engines, there is nothing to stand in the way of cartage by steam-power but the want of good roads about the farm, which are an essential point in a highly cultivated farm, whether steam cultivation be employed or not. The experience lately gained in the use of the traction-engine is, that loads can be conveyed over moderately good roads at an expense of 2*d.* a-ton the mile; and there is therefore no doubt that the farm cartage can also be done economically. This operation will require some time to develop itself, as the vehicles for conveying the materials will have to be bought, and proper roads made in every direction through the farm, before steam cartage can be carried on conveniently; but at present there can be no reason why all corn should not be taken to market, and coals and so forth brought back, by steam-power. At the time this was written Fowler and Greig had no doubt that before ten years' time two-thirds of the cartage of the farm would be generally done by steam, and also that the railways would be fed by traction-engines, and that these would become quite common: although, through mistaken ideas, serious attempts had been made to stop their use on the public roads. This prediction is being carried out, for it has been proved that a 10-horse engine will convey a load of 20 tons independent of itself over a road with gradients not exceeding 1 in 15; and the wear and tear is very slight indeed in properly constructed traction-engines.

In order properly to understand the advantages of steam cultivation, it is necessary to draw a contrast between steam-power and horse-power as applied to cultivation.

In the case of horses, the utmost available force which can possibly be brought to bear on an implement is 9 cwt., and this is obtained by employing six horses, or two more than can work profitably together on the land. The practical limit of draught is therefore 6 cwt., as horses cannot give off the same amount of draught in the fields as on hard roads. Hence with a team of four horses giving off 6 cwt. total draught on an implement which acts on a width of land of from 10 to 12 inches, the utmost total power for an inch in width of the soil acted upon will be only 70 lbs. At the same time the resistance will be very much increased by the pressure of the horses' feet in doing the work. For if a horse be taken when the land is in a rather plastic state, and walked across the track of the steam-plough, and made to travel to and fro transversely on every 10 inches width until a breadth of 6 yards is trodden over, it is then found that if the steam cultivator has just sufficient steam to perform its work properly before it arrives at the ground so trodden down, it will be completely stopped before it gets through the 6 yards; and considering the momentum of the flywheel, this experiment shows plainly that the power required is something very material, and experience shows one-third additional draught to be required on land that has been trodden down to the same extent as in cultivation by horse-power. It is clear therefore that a considerable part of the 6 cwt. draught of the horses is expended in undoing the compression caused by their own weight; and as the 4 tons' weight of the horses themselves must be lifted up and down all the inequalities of the ground, there is only a very small portion of the animal force left to be usefully exerted upon the implement, and this only at the slow speed of 1½ mile an hour, at which the horses travel.

But with steam the case is very different: a draught of 35 cwt. is available upon the implement, giving the farmer the means of employing a force of from 70 lbs. to 280 lbs. to each inch in width of the soil moved. And considering that only a 1¼-ton load is passing over the land instead of 4 tons, much less force is employed to move the same measurement of soil.

The comparison therefore stands thus:—With horses there is a total force of 6 cwts., with the drawback of having to convey 4 tons of useless load over the land; while with steam-power there is a total force of 35 cwt. conveying only 1¼ ton of useless load. The result of experience is, the less weight carried over the land the better; and when the great weight of horses, compared with the force they exert, is considered, and also the number of footprints left by them on an acre, it cannot but excite surprise that such an unmechanical means of cultivation should have existed so long. The number of footprints left by four horses in ploughing a 12-inch furrow is above 300,000 per acre; whereas the steam-plough, which has a width of from 3 to 4 feet, is carried on two wheels 6 inches in width.

The facts that have been stated afford a good reason why horses should be kept off the ground altogether. If the necessary precautions in this respect are but strictly followed, a complete revolution in agriculture would soon be witnessed, as no mechanical means of pulverizing the land is required, and less than one-half the number of operations at present necessary would be found sufficient.

Land, like metal in a furnace, requires the greatest attention in order to perform the different operations at the same time, when it is in the right state for their being effected thoroughly. The present system of management is entirely inadequate to effect this object, from the want of sufficient force at a given time. In some years there are barely two months suitable for all the cultivation of the season: that is, provided the greatest judgment is exercised, and the land never touched except when in the proper state for the purpose of cultivation. But with such management as is here recommended, the result will be always an adequate crop.

The advantages of steam cultivation having now been described, and its gradual development during the past few years having been traced, together with the various systems employed, it is proposed in conclusion to enumerate what may be considered as the principal points which are essential to the production of good steam-cultivating machinery, so far as regards its mechanical arrangements.

First, a sufficiently powerful engine with a wide bearing surface, and plenty of leverage to move itself out of difficult situations, and of simple construction in all its parts.

Second, a hauling apparatus with a drum of large diameter, and so arranged as to bend the rope as seldom as possible and with the drum placed horizontally on a vertical axis, so as to allow the rope to work in any direction without requiring guide pulleys.

Third, a direct pull upon the implement, with as short a length of rope as possible, and that of good quality, light, hard, tough, and flexible.

Fourth, an arrangement for keeping the rope tight, so as to carry it clear of the ground and avoid loss by friction.

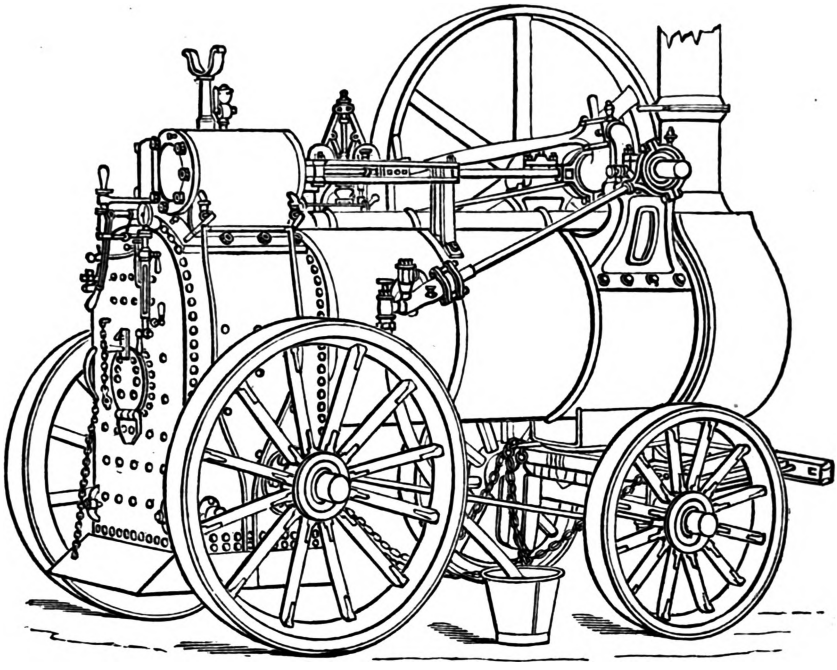
Fifth, an implement in which the shares or tynes follow each other consecutively, wedging off the soil to a loose side.

Lastly, as small an amount of manual labour as practicable.

AGRICULTURAL ENGINES. Fr., *Machines à vapeur locomobiles appliquées à l'agriculture;* Ger., *Dampfmaschinen verwendet zu landwirthschaftlichen Zwecken;* Ital., *Macchine a vapore agricole;* Span., *Maquinaria agrícola.*

The portable agricultural steam engine of Holmes and Sons, of Norwich, is shown in Fig. 86. The construction of this engine is simple; the working parts being all outside, the whole can be

86.



adjusted readily. It is fitted with a *cranked shaft*, so that a wheel or driving drum can be fixed at either side. It has a *governor*, of simple form, having few parts, which works with precision. Every part of the engine is of great strength, wrought iron being used where practicable. The *piston-rod*, pins, and small parts are made of steel. All the brass bearings are wide and easy to adjust. The *feed-pump* is fitted so as to prevent any liability of accident in frosty weather, and in such a manner that it cannot easily get out of order. The *boiler* is of sufficient capacity, and capable of doing heavy work without priming. The *cylinder* is large, with 14-inch stroke.

The engine of Ransomes and Sims, Fig. 87, is specially designed and constructed to economize fuel and to regulate its consumption according to the power required. It has a *feed water-heater*, or reservoir placed in the *smoke-box* of the engine, in which the water is heated by the exhaust steam and hot air passing from the *fire-box* to the *chimney*. A double feed-pump is in connection with this heater by means of pipes shown on the side of the engine. One pump draws the cold water from the supply tank and discharges it into the heater. The other is supplied with hot water from the heater, and forces it into the boiler. The *slide-valve* is on the gridiron principle, and the pressure of the steam is removed from the back of the *valve* by means of metallic equilibrium relief-rings kept up to the faces of the *slide-case cover* by means of spiral springs; these valves are found to be as easily moved when the steam is on as when it is off. The *cut-off*, or expansion-valve, is worked by a movable *eccentric*. The adjustment of this eccentric is very simple; it is held in its place by a nut screwed to a bolt fixed to the fast eccentric, under which is placed a pointer, which slides on a plate graduated with the various grades of expansion, and fixed to the other eccentric, and the engine-driver has only to adjust the loose eccentric until the pointer reads the mark in the grade which corresponds with the point at which the steam is cut off in the stroke of the piston. The general construction of the engine is very strong. The average consumption of fuel is about 3·5 lbs. of ordinary coal an hour.

*Clayton, Shuttleworth, and Co.'s Portable Steam Engine.*—This engine, Fig. 88, in its construction presents a method of heating the exterior surfaces of the cylinder and *steam chest*. The cylinder is placed in the smoke-box surrounded by a *jacket* forming an annular space, which, being filled with steam, heats the cylinder, and, at the same time, protects it from the injury that would be caused by direct contact with the heated gas. By this arrangement condensation and radiation are prevented.

There has been a great objection to placing the cylinder and steam chest in the interior of the

boiler, as it rendered the engine more difficult to examine and repair; but in the engine under notice this has been obviated by leaving both ends of the cylinder and steam chest exposed; the

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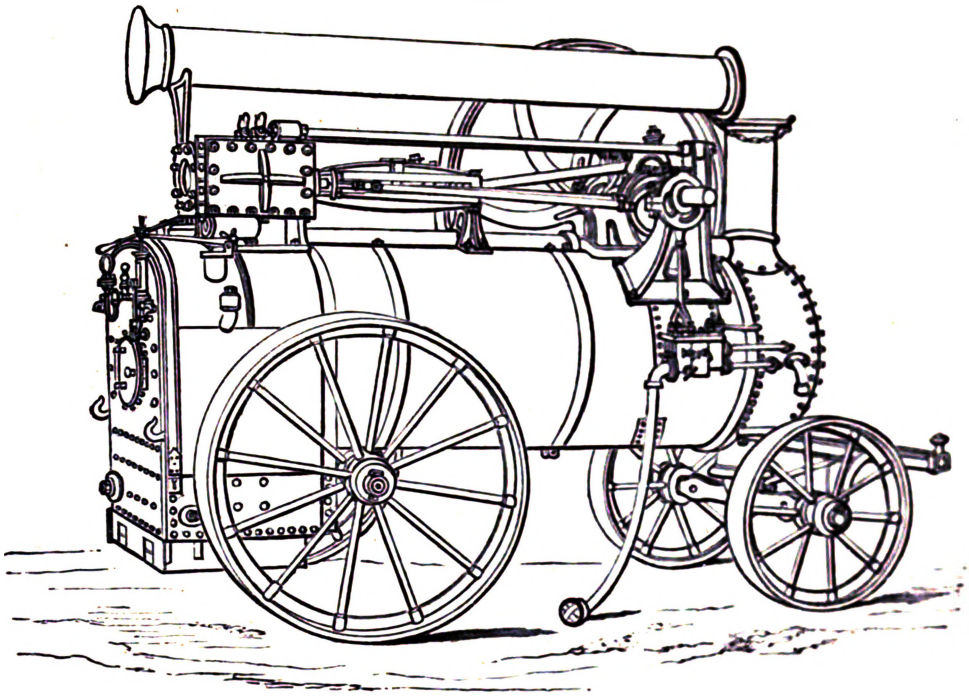

covers can be removed, and the piston and slide-valve cleaned or adjusted as expeditiously as in an outside cylinder engine. This engine is also made to reverse. See ENGINES, *varieties of*.

*Works appertaining to this subject :—*

'The Implements of Agriculture,' by J. A. Ransome, royal 8vo, 1843.

'The Farm Engineer, a Treatise on Barn Machinery,' by R. Ritchie, royal 8vo, 1849.

'Agricultural Engineering,' by G. H. Andrews, 12mo, 1852-3.

'On Steam Cultivation,' by John Fowler, jun. Proceedings Inst. Mechanical Engineers, 1857.

'The Book of Farm Implements,' by James Slight and R. S. Burn, royal 8vo, 1858.

'The Official Illustrated Catalogue of the Exhibition of 1862,' British Section, 2 vols., imperial 8vo, 1862.

'On the Application of Steam Power to Agriculture,' by John Fowler and D. Greig. Proceedings Inst. Mechanical Engineers, 1865.

'Steam Cultivation,' Engineering, vol. iv., 1867.

'Études sur l'Exposition,' 1867. Lacroix, Paris, 1867-8.

'On Steam Cultivation,' by Baldwin Latham. Transactions of the Society of Engineers, 1868.

'Officieller Ausstellungs-Bericht herausgegeben durch das K.K. Österreichische Central-Comité.' Vienna, 1868.

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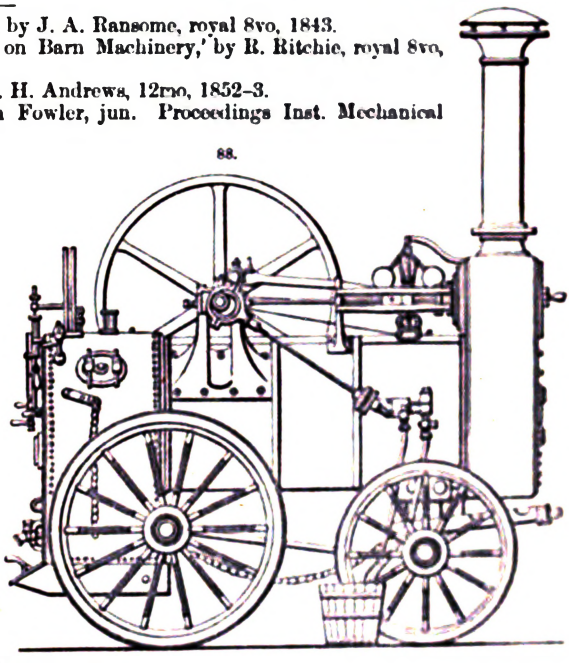


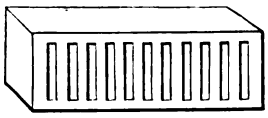
AICH'S METAL. FR., *Métal d'Aich*; GER., *Aich's Metall*; ITAL., *Lega d'Aich*; SPAN., *Metal de Aich*. See ALLOYS.

AIR-BRICK. FR., *Brique creuse*; GER., *Hohlziegel*; ITAL., *Grata dello sparaglio, dello sbalzatoio*; SPAN., *Ladrillo perforado*.

An air-brick is a brick of the ordinary size, made of earthenware, built into the walls of a

building, but perforated, Fig. 89, to admit air under the floors or into the rooms. It is sometimes made of cast iron, with a slide worked by a small knob, Fig. 90, to enable the openings to be closed if required.

89.



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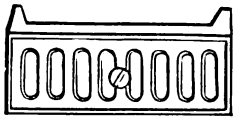


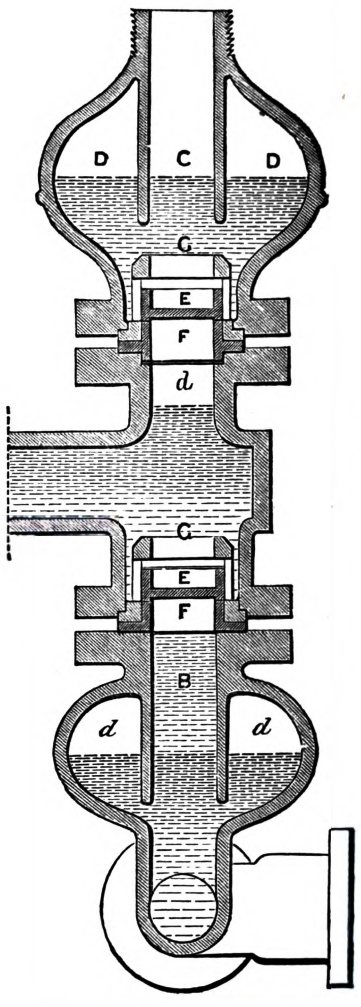
AIR-GRATING is similar to an air-brick, but of larger size and of less thickness in proportion to its other dimensions. It is used as in the case of the air-brick, to admit air to the interior of buildings.

AIR-CHAMBER. FR., *Chopinette, trachée, réservoir d'air*; GER., *Windkessel, Windraum*; ITAL., *Serbatoio d'aria*; SPAN., *Cámara de aire.*

A cavity containing air to act as a spring for equalizing the flow of a liquid in pumps and other hydraulic machines.

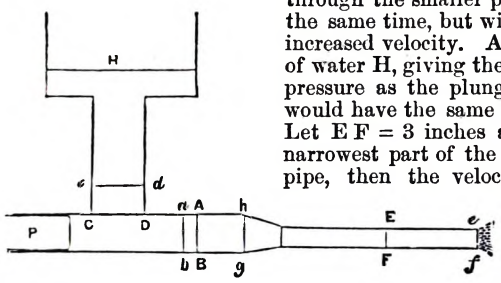
Fig. 91 is a section of a locomotive feed-pump; the water is drawn in by the action of the plunger in the barrel A, through the feed-pipe B, and valves E, which rest on their seats F, and held in place by the cages G; the water entering the air-chamber D, in the top of which the air is compressed, forcing the water out of the delivery-pipe C beyond its middle position when the piston is at the end of its stroke. The feed-pumps of American locomotives are supplied with air-chambers *d*, *d*, on the suction side, as well as D, D, for the delivery. This pump was invented by Walter McQueen, an American engineer. The elastic force of the cushions D, *d*, of condensed air in the air-chambers, relieves the pipes, valves, and joints from sudden shocks; besides, the action of the air by its alternate compression and expansion secures a steady supply of water to the boiler. The barrel of the pump is generally of brass, the plunger, working in the pipe A, a solid bar of iron. The valves are of the cup form, Fig. 91. The rise of the valves is seldom more than $\frac{1}{4}$th of an inch; and sometimes, while the rise of the inlet-valve is restricted to $\frac{1}{4}$th of an inch, the delivery-valve rises only $\frac{3}{16}$ in. and the cheek-valve $\frac{1}{8}$.

91.




If a plunger P, Fig. 92, working in a pipe P A B, $5\frac{1}{2}$ inches in diameter, forces the water *a b g h*, 9 inches from *a* to *g*, into a smaller pipe *h f*, in a second, the same quantity of water passes through the smaller pipe in the same time, but with an increased velocity. A head of water H, giving the same pressure as the plunger P, would have the same effect. Let E F = 3 inches at the narrowest part of the small pipe, then the velocity of

92.




the water at E F will be 30·25 inches a second, while at A B in the larger pipe the velocity is only 9 inches a second; for $\frac{(5\cdot5)^2 \times 9}{3^2} = 30\cdot25$. Now let W be the weight of a column of water which produces the pressure P, which may be supposed constant, and put *t* for the time of its operation, long or short, and $m = \frac{W}{g} = \frac{W}{32\cdot2}$; whence $P\,t = m\,v$, *v* being the velocity, therefore $P = \frac{m}{t}\,v$. This expression shows that the effort required to impart or destroy a quantity of motion *m v* is so much the greater as the time employed is less: and since the reciprocal action of bodies is more rapid compared to the spaces described, their compressions, flexures, and penetrations are less for the same quantity of motion destroyed.

We have here explained why the shock of hard bodies, the transmission or destruction by bodies slightly flexible, compressible, or extensible, occasion such great efforts and such ruptures and accidents; and how it is, on the other hand, by the interposition of soft and compressible bodies, that the intensity of efforts and their consequences are so much diminished. We may see by the expression $P = \frac{m}{t}\,v$ that a finite velocity could never impart in an infinitely small time to a mass *m*. except by an infinite effort, which shows the error in the hypothesis of the instantaneous transmission of

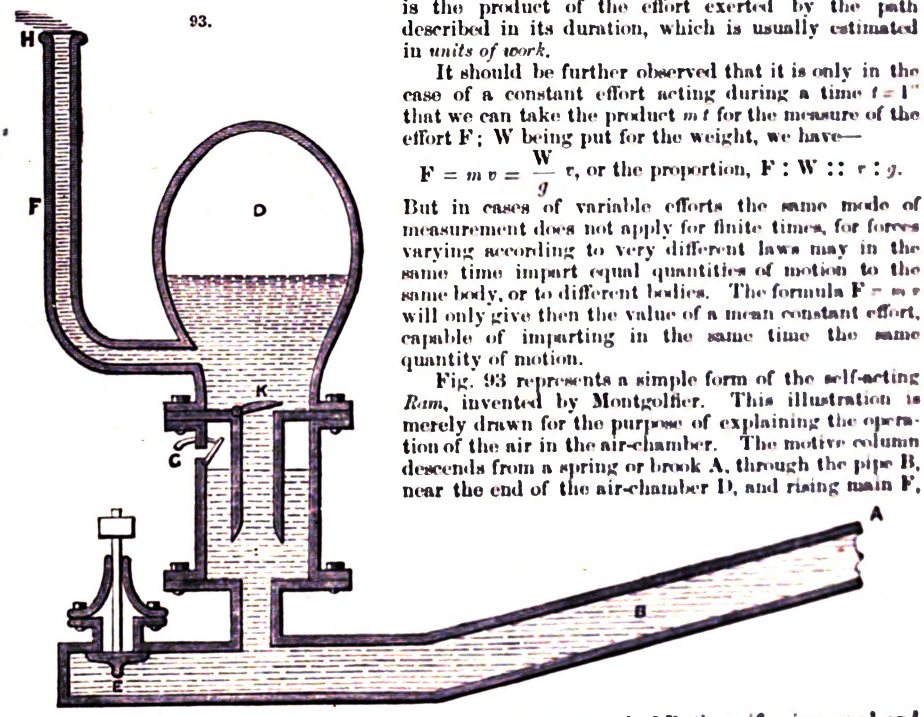
motion by forces, to which we are then compelled to give a special name, and thus suppose a special nature in calling them *forces of percussion*. This error is often too explicitly admitted in the teachings of rational mechanics. Nothing like an instantaneous operation really occurs in nature; quantities of motion are imparted and destroyed in greater or less periods of time, sometimes, indeed, imperceptible to our senses and means of observation, but never instantaneous.

Suppose the force acting on the plunger to be 48·3 lbs. on the square inch, and that it is required to find the pressure acting on a valve at $e\,f$, which valve opens $\frac{1}{4}$ths of an inch against the action of a spring; then $\frac{48\cdot3}{32\cdot2} = \frac{3}{2} = m$; we have before shown that the velocity of the water in the small pipe E $f$ = 30·25 inches a second, = $\frac{30\cdot25}{12}$ feet a second; whence the force acting on each square inch of the valve will be—

$$\frac{3}{2} \times \frac{242}{7} = \frac{30\cdot25}{12} = 130\cdot7 \text{ lbs.}$$

for the time the water in the small pipe is moving over $\frac{7}{8}$ in. = $\frac{7}{96}$ ft. = $\frac{7}{242}$ seconds. When the spring at $e\,f$, or the pressure of the water and steam in a boiler, becomes too great to be overcome by the action of the plunger P, the air in the air-chamber D, Fig. 91, by being condensed, conservates the balance of the force of the water passing through the small pipe, and delivers such concentrated force when the plunger injects more water. Care should be taken in making use of what is here termed the quantity of motion or *momentum*, for when we know the product of the mass $m$, of a body, and the velocity imparted to, or taken from it, we have the measure of effort produced by the force during the period of action; but we see that this measure cannot be taken as a term of comparison except for analogous cases, where the velocities are really imparted or destroyed by force; and it does not follow that the product P $t$, of the force, by its period of action (equal, when there is a change of motion, to the quantity of motion imparted or destroyed), should always serve as a measure of the effort of forces, as is sometimes admitted for certain instruments and certain kinds of work. It is often seen that an effort may continue a long time without producing a mechanical effect. Thus, horses pulling upon a mired waggon, without starting it, develop considerable efforts, which multiplied by the period of their action would give an enormous product without any useful effort resulting in any mechanical work, and nothing but fatigue and exhaustion of the horses. Take, for example, the draught of a plough, which in strong earth requires a mean total force of 794 lbs. Suppose the furrow to be 400 feet long, the horses in one take 100″, and in the other 200″ to plough it. We shall have in the first case, P $t$ = 794 × 100″ = 79,400; and in the second, P $t$ = 794 × 200″ = 158,800; and yet in both cases they have accomplished the same work. An instrument giving the product of efforts by the times or periods of duration would by no means lead to an exact appreciation of the mechanical effects produced. The true measure of these effects is the product of the effort exerted by the path described in its duration, which is usually estimated in *units of work*.

93.




It should be further observed that it is only in the case of a constant effort acting during a time $t$ = 1″ that we can take the product $m\,t$ for the measure of the effort F; W being put for the weight, we have—

$$F = m\,v = \frac{W}{g}\,v, \text{ or the proportion, } F : W :: v : g.$$

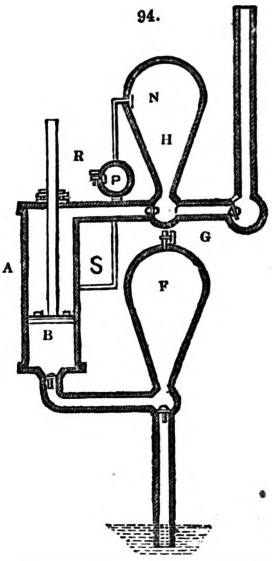
But in cases of variable efforts the same mode of measurement does not apply for finite times, for forces varying according to very different laws may in the same time impart equal quantities of motion to the same body, or to different bodies. The formula F = $m\,v$ will only give then the value of a mean constant effort, capable of imparting in the same time the same quantity of motion.

Fig. 93 represents a simple form of the self-acting *Ram*, invented by Montgolfier. This illustration is merely drawn for the purpose of explaining the operation of the air in the air-chamber. The motive column descends from a spring or brook A, through the pipe B, near the end of the air-chamber D, and rising main F, which are attached, as shown in the figure. At the extreme end of B, the orifice is opened and closed by a valve E. This valve opens downwards, and may be either a spherical one or a common spindle valve, as shown in the figure. It is the play of this valve that renders the machine self-acting. To accomplish this, the valve is made of, or loaded with, such a weight as just to open when the water B is at rest, that is, it must be so heavy as to overcome the pressure

against its under-side when closed, as represented in Fig. 93. Now supposing this valve open, the water flowing through B soon acquires an additional force that carries up the valve against its seat; then a portion of the water will enter the air-chamber D and rise in F, the valve of the air-chamber preventing its return. When this has taken place, the water in B has been brought to rest, and as in that state its pressure is not quite sufficient to sustain the weight of the valve, E opens, descends; the water in B is again put in motion, when its whole pressure begins to act, and again closes E, as before, when another portion is driven into the air-vessel D, and pipe F; and thus the operation is continued, as long as the spring affords a sufficient supply and the apparatus remains in order. The pressure which closes the valve E is that due to the short range of the valve and the increased velocity acquired by the water in passing from a large to a smaller pipe. The surface of the water in the spring or source should always be kept at the same elevation, so that its pressure against the valve E may always be uniform, otherwise the weight of E would have to be altered as the surface of the spring rose and fell.

This ingenious machine may be adapted to numerous localities in every country; but when the perpendicular fall from the source to the valve E is but a few feet, and the water is required to be raised to a considerable height through F, then the *length* of the ram or pipe B must be increased, and to such an extent that the water in it is not forced back into the spring when E closes, which will always be the case if B is not of sufficient length. If a ram of large dimensions, and made like Fig. 93, be used to raise water to a great elevation, it would be subject to an inconvenience that would soon destroy the beneficial effect of the air-chamber D. For if air be subjected to great pressure in contact with water, it in time becomes incorporated with or absorbed by the latter. This sometimes occurs in water-rams like this, for when used they are incessantly at work both day and night. To remedy this, Montgolfier ingeniously adapted a very small valve, opening inwards to the pipe beneath the air-chamber, and which was opened and shut by the ordinary action of the machine. Thus, when the flow of the water through B is suddenly stopped by the valve E, a partial vacuum is produced immediately below the air-chamber D by the recoil of the water, at which instant the small valve opens, and a portion of air enters and supplies that which the water absorbs. Sometimes this *Snifting-valve*, as it has been named, is adapted to another chamber immediately below that which forms the air-chamber, as at G. In small rams a sufficient supply of air is found to enter at the valve E. The compressed air in D not only conservates the work expended in raising the water to H, but also the work required to overcome the friction of the water in the pipe F H; and consequently the air in the air-chamber has the power to close the valve K when the water at H begins to return.

94.




P. H. Vander Weyde has invented a second air-chamber, Fig. 94, to be attached to the induction-pipe, which has a small opening by which air is admitted from without. By the operation of the pumps, air is gradually withdrawn from this chamber and conducted to the principal air-chamber attached to the delivery-pipe.

H and F are air-chambers, P and N valves, and R and G stop-cocks, all arranged so as to supply the constant loss of air taking place in air-chambers. See HYDRAULICS. PUMPS.

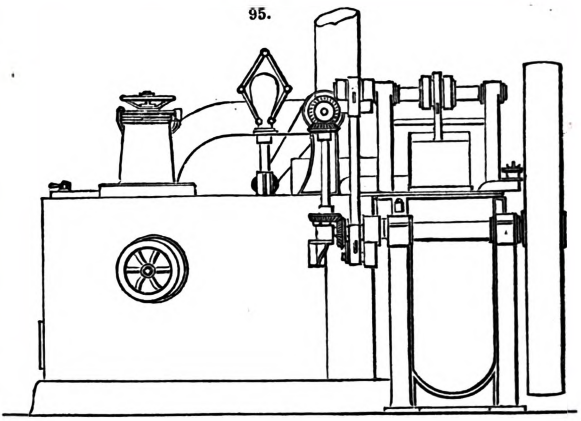
AIR-DRAIN. FR., *Conduit d'air;* GER., *Luftkanal;* ITAL., *Condotto d'aria;* SPAN., *Alcantarilla para la conduccion de aire.*

A cavity in the external walls of a building, to prevent dampness, is called an air-drain.

AIR-ENGINE. HEATED-AIR ENGINE.

AIR-ENGINE. FR., *Machine à air chaud;* GER., *Atmosphärische Maschine;* ITAL., *Macchina ad aria calda;* SPAN., *Máquina de aire.*

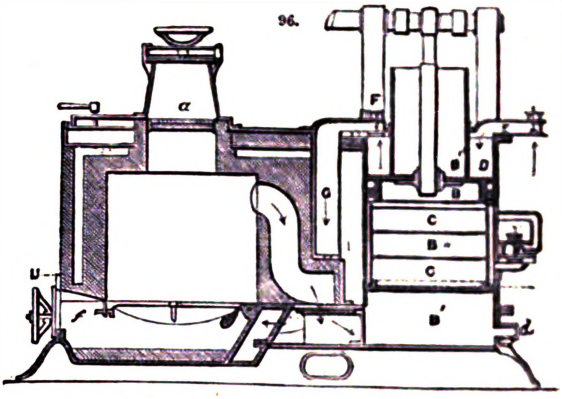
95.



The engine, Figs. 95, 96, 97, 98, invented by Philander Shaw, works with heated air in a close combustion chamber, where it comes in direct contact with the fuel, and is mixed with the gaseous products of combustion. The air and gases pass through the engine, and effect its movement, part of the power being made use of to pump fresh cold air into the combustion chamber. There is no special air-pump provided for this purpose, as the cylinder is made single-acting, and the piston has a large trunk which forms an annular space in the cylinder, and the latter is made use of to act as the air-pump. This arrangement has the advantage of keeping the cylinder cool, since part of its surface is always in contact with cold air. There are two cylinders having their pistons connected together by a beam, so as to form conjointly a double-acting engine, each single-acting cylinder acting during the return stroke of the other. The two cylinders A, A, Fig. 97, and their arrange-

ment, are shown in section in Fig. 96. Fig. 97 shows a section of the engine on a horizontal plane. The combustion chamber is a vessel constructed of boiler plates, and lined with two rows of fire-bricks, all round between which a passage is left for the circulation of air. The air, passing in cold, takes up the heat from the inner row of bricks, and prevents the outer row becoming very hot and wasting heat by radiation. The piston B, Fig. 96, carries the trunk B', which leaves the annular space D to act as an air-pump, the valves E and F regulating the inlet of the cold air in the down-stroke, and its outlet into the combustion chamber during the up-stroke. There is a regenerator or air-heater interposed between the air-pump and the combustion chamber; this is shown at K, Fig. 98; it consists of a series of vertical pipes, through which the exhaust air from the engine passes up a chimney. The waste heat of this air is utilized in the regenerator by being partly taken up by the cold air passing outside the tubes and arriving at the combustion chamber at a higher temperature. The fire-door is at the top of the chamber, which is provided with a dome *a*, Fig. 96. The grate is slightly inclined towards the ash-door *f*. All these doors are carefully closed during the working of the engine, as the pressure within would be reduced by leakage. The valves are worked by cams and levers, and no special arrangements are required, in working this engine, to keep the cylinder cool.

96.

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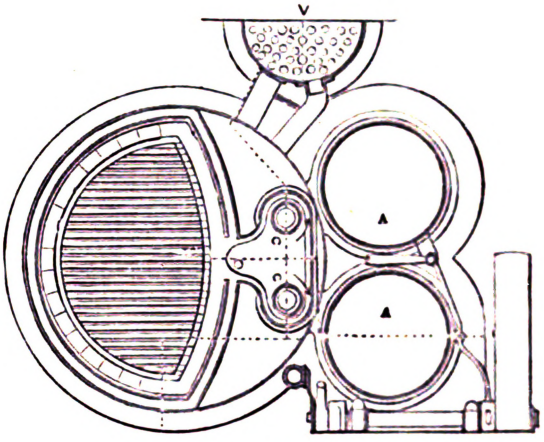


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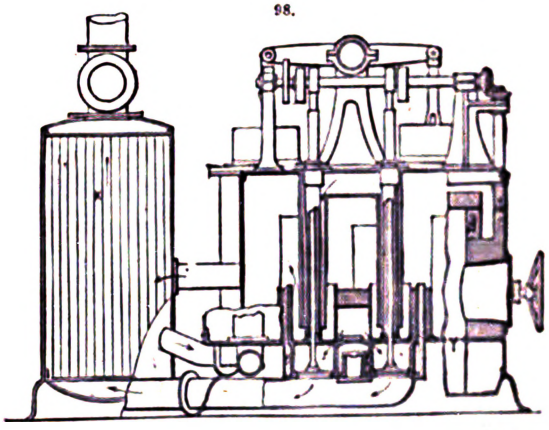
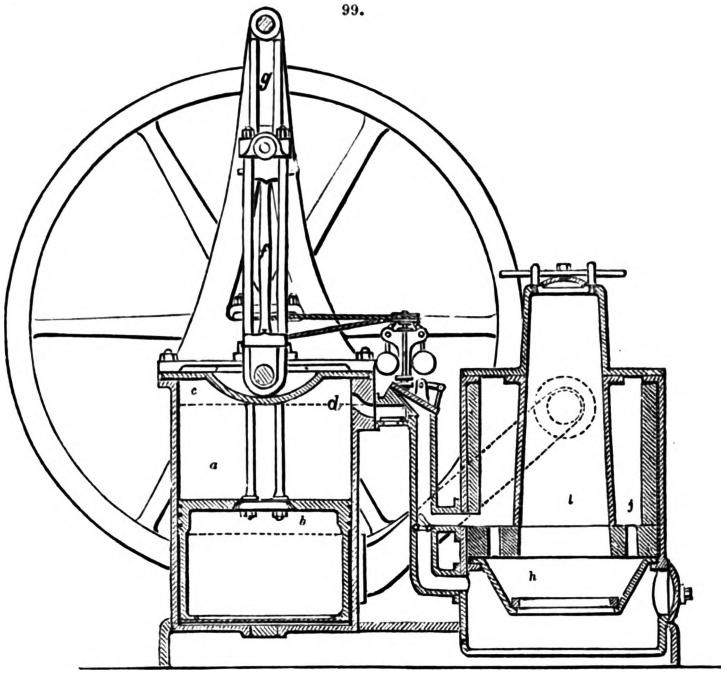


By another arrangement, which we illustrate in the annexed engravings, Figs. 99, 100, 101, the upper end of the cylinder *a*, Figs. 99, 100, is made of such capacity that when the piston *b* reaches the top of the stroke at *c*, a space *d* may be left, in which the portion of air not required may be compressed, and, consequently, will not enter the furnace, and, by its subsequent expansion, will assist the down-stroke of the piston. This space may be formed between the piston and cylinder lid, or the air may be compressed in a side passage or reservoir. In these engines Wenham prefers carrying the crank shaft *e*, in bearings bolted to the top of the flange of the cylinder, and working the crank by a return connecting rod *f*, with the guides *g*, from the piston-rods above, similar in form to that known as a *steeple engine*; in other respects, as in the furnace and valve arrangements, the parts are substantially the same as in most hot-air engines, constructed by others as well as Wenham. In the enigne, Figs. 99, 100, however, Wenham places a disc of fire-clay above the furnace, as shown at *h*, Fig. 99; this is supported on the rim of the fire-pan, and has a central hole, equal in diameter to the bore of the fuel hopper *l*, which touches the disc, and the bottom edge is thus protected from the direct heat of the fire. Around the disc are a series of perforations, J, shown in plan, Fig. 101, leading to the annular space of the stove; a jet of pure flame rises through each of these at every stroke of the engine, and at the same time the fire is prevented from rising above its proper level.

AIR-ESCAPE. Fr., *Appareil pour l'échappement de l'air*; Ger., *Vorrichtung zum entweichen der Luft*; Ital., *Sfiatatoio*; Span., *Venteador*.

An air-escape is a contrivance for letting off the air from water-pipes. It consists of a hollow ball F, Fig. 102, attached to the upper part of the pipe, in which a ball-cock C is placed, adjusted in such a way that when any air collects in the pipes A and E, it will ascend in the vessel, and, by

99.

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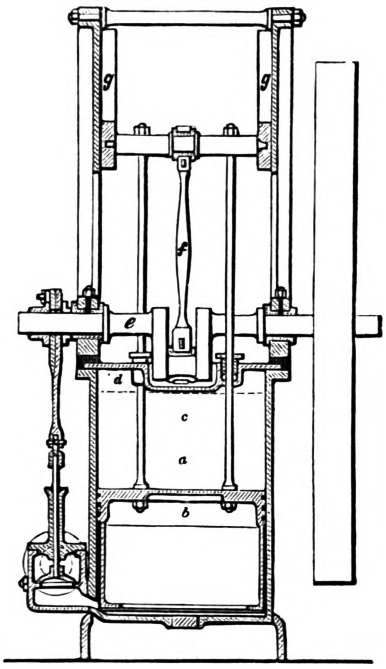


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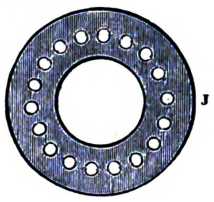


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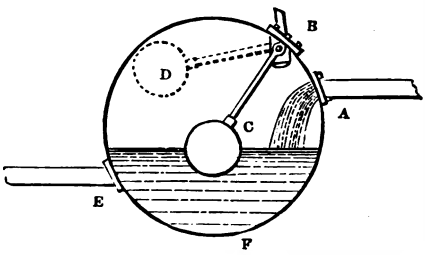



displacing the water, cause the ball to descend, and thus open the cock B, and allow the air to escape. No water, however, can follow it, for when the fluid rises to a certain height the ball rises to D, and shuts the cock.

AIR-GUN. Fr., *Fusil a vent*; Ger., *Windbüchse*; Ital., *Schioppo ad aria*; Span., *Fusil de viento.*

An air-gun is an instrument resembling a musket, made to discharge projectiles by the force of compressed air.

AIR-HOLES. Fr., *Soufflures*; Ger., *Luftblase*; Ital., *Bolle d'aria*; Span., *Respiraderos.*

Holes or cavities in a casting, produced by bubbles of air in the liquid metal, are termed air-holes.

AIR-PIPES. Fr., *Ventilateurs, Conduit ou carreau à air*, Ger., *Luftröhren*, Ital., *Tubi dell'aria; Tubi da Ventilazione*; Span., *Ventiladores.*

Air-pipes are pipes used to draw foul air from a ship's hold, mines, and other close places.

AIR-PUMP. Fr., *Pompe à air, machine pneumatique*; Ger., *Luftpumpe*; Ital., *Tromba, Macchina pneumatica*, Span., *Bomba de aire.*

Any pump or machine employed to exhaust the air from a closed vessel is termed an air-pump.

In the air-pump designed by E. S. Ritchie, Fig. 103, the lower valve is conical, held in place by a triangular stem fitting the tube; it is raised by the valve-rod passing up through a stuffing-box in the piston. An enlarged section, Fig. 104, shows the manner in which the attachment is made which allows a motion of the rod sidewise, so that any slight change of form of the packing of the piston, or stuffing of the rod, cannot prevent the valve from shutting properly. The cone of the valve is ground to a perfect fit to its seat, but the valve is also furnished with a disc of oiled silk, which projects just beyond its outer edge, and touches the flat surface of the valve-seat; the valve-rod extends up, and its upper end is secured in a hole drilled in the upper plate, of depth sufficient to allow motion vertically to open the valve. The piston is of thick brass, made in two parts; the upper piece has a hole drilled larger than the piston-rod, the lower part of a conical form, ground to fit a cone on the piston-rod; this forms the piston-valve. The lower piece of the piston covers the end of the piston-rod, but allows it enough motion to open the valve; a series of small holes through the plate gives a free passage for the air to the valve. A third valve is placed outside the cylinder, made of oiled silk in the usual way. In the upper plate of the cylinder is inserted a steel lever, one end of which covers the valve-rod, the other end, when the lower valve is closed, is flush with the plate, but when the valve is raised it projects into the cylinder.

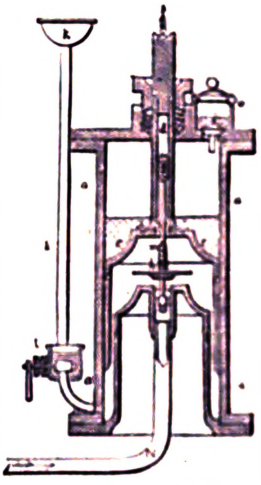
103.

104.

In action the first motion, upward, of the piston-rod closes the piston-valve; the first motion of the piston opens the lower valve; as the piston ascends, the air above it is forced out through the upper valve and air from the receiver flows unobstructedly into the cylinder. The piston strikes the tail of the lever, and at the instant of arriving at the top closes the lower valve. The first downward motion of the piston-rod opens the piston-valve, the air remaining in the interstices above the piston distributes itself equally throughout the cylinder, but none can pass the lower valve back into the receiver. When the piston again reaches the bottom of the cylinder, the interstices below are filled with air as rarefied as a pump with ordinary valves can exhaust.

The air-pump of Robert Gill, Fig. 105, consists of a cylinder *a*, to the lower flange of which the bell-mouthed vessel *b*, projecting upwards into the cylinder, is secured. Between the outer side of the vessel and the inner side of the cylinder, the tubular bell-shaped piston *c* is situated. The hollow piston-rod *d* is screwed into the upper part of the piston, and the leather flap-valve *e* is held firmly between these two parts by the gripping action of the screw. The lower part of the piston-rod *d* is tubular, and a small leather-packed piston *f* is fitted to the rod, carrying at its lower end the valve *h*. A part of the rod above the valve *h* is encircled by a helical spring. The upper cover of the cylinder is provided with an air-escape valve *i*, which is immersed in a reservoir of oil to ensure its tightness, and the air extracted from the receiver escapes through the small hole *o*. The cup and tube *k* are used for supplying the liquid to the cylinder.

105



To prepare the apparatus for work, the upper cover of the cylinder is taken off, and the cock *l* opened. The fluid is then poured down the tube *k* into the cylinder until the piston is completely covered, the cover being replaced and the cock shut, the apparatus is then ready for action. On moving the piston upwards, the valve *h* would, if free, be also drawn up by the friction of the small piston *f* in the tubular piston-rod. The spring *m*, however, is of greater length than the distance between the under side of the piston *c* and the valve *h* when the piston is at its lowest position, consequently the spring *m* is compressed until the piston *c* is raised through a distance corresponding to the length of the spring. Being in this state, the elasticity of the spring overcomes the tendency to raise the valve *h*, produced by the friction of the small piston *f*; the valve *h* is therefore maintained close against its seat until the elasticity of the spring ceases to act, or, in other words, until the piston *c* is elevated through a distance equal to the spring length, on arriving at which point the valve *h* begins to rise. The foregoing arrangement of the spring and valve is necessary for the following reason —If the valve were free to rise, the apparatus being charged with oil, some of it would flow through the valve opening, and enter the tube leading to the receiver, into which it might pass. As the piston, however, is raised higher, its tubular part being gradually emerged from the annular space in the lower parts of the cylinder, the level of the oil under the piston is lowered, the space for holding the liquid being gradually enlarged, so that the valve is left uncovered by it. The apparatus is shown in the figure in the position of inaction of the spring, and with the valve open.

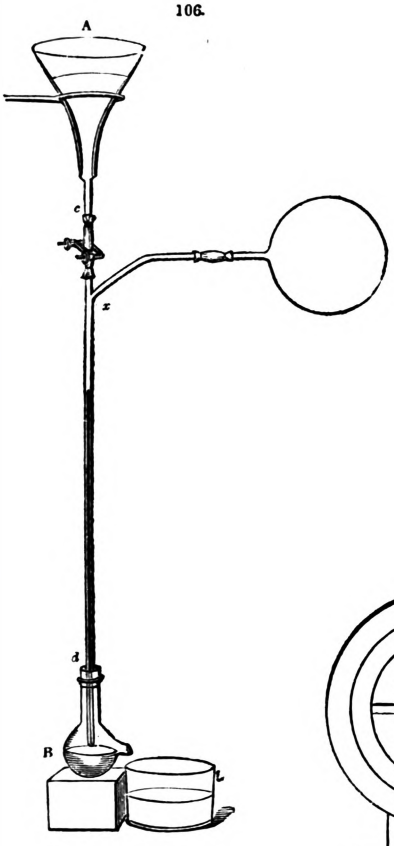
Before raising the piston the space below it is completely full of oil, and the joints through which air might intrude are all covered with this liquid; consequently, the space left by the motion of the piston must remain perfectly empty, at least as regards air. The vacuous space below the piston being now in communication with the receiver through the tube N, becomes filled with air more or less rarefied; at the same time the air contained in the upper part of the cylinder being compressed by the ascent of the piston, raises the valve *i*, and escapes into the atmosphere through the aperture *c*. As the pressure above the piston is greater than that below it, a small

leakage of oil takes place downwards through the interstice round the little piston-rod, and dropping upon the shield attached to the valve *h*, falls into the annular space, and there accumulates during the ascent of the piston. The interstice for leakage allows only a small quantity of oil to pass, otherwise the valve *h* might be overflowed before the piston begins to descend, and consequently before the valve was closed. It will be seen that in every part of the piston's motion its lower edge is immersed in the oil, which prevents any lodgment of air between it and the sides of the cylinder.

At the commencement of the downward motion of the piston, the valve *h* is closed immediately by its piston *f*, and the valve *i* is closed by its own weight and the atmospheric pressure; the space below the piston becomes smaller and smaller as the piston descends; at the beginning of the upward stroke all the space below the piston was full of oil, and during the upstroke more oil has passed down into the annular space; the consequence is, that when the piston reaches the bottom of its stroke, the space below being completely full, it is evident that the air extracted from the receiver must be completely expelled through the apertures *e e*, together with that small quantity of oil which passed downwards through the interstice around the rod, during the ascent of the piston. The space below the piston is thus infinitesimally reduced, and consequently the air is completely expelled, however rarefied it may have been on entering from the receiver.

The most perfect air-pump is that invented by Hermann Sprengel, Fig. 106, which consists of a glass tube *c d*, longer than a barometer, open at both ends, and in which mercury is allowed to fall down, supplied by the funnel A, with which the tube is connected at *c*. The lower end *d*, of this tube dips into a small glass bulb B, into which it is fixed by means of a cork. This glass bulb has a spout at its side, situated a few millimètres higher than the lower end of the tube *c d*. The first portions of mercury which run down will consequently close the tube, and form a safeguard

106.

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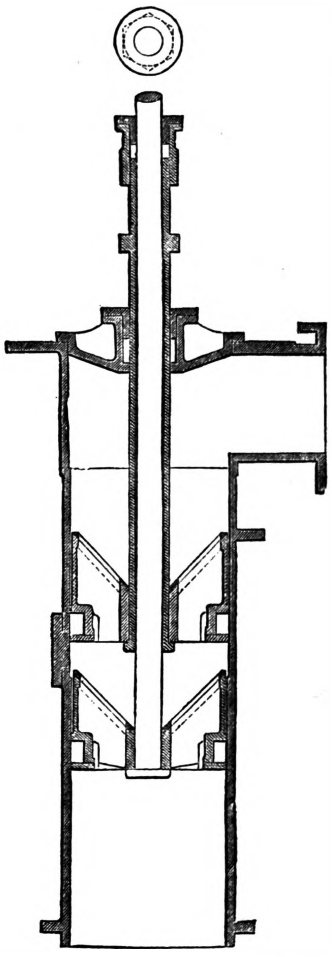

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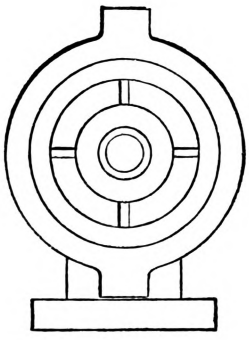


against the air which might enter from below, if the equilibrium should be disturbed. The upper part of *c d* branches off at *x* into a lateral tube, to which the receiver R is affixed. As soon as the stop-cock at *c* is opened, and the mercury allowed to run down, the exhaustion begins, and the whole length of the tube, from *x* to *d*, is seen to be filled with cylinders of mercury and air, having a downward motion. Air and mercury escape through the spout of the bulb B, which is above the basin H, where the mercury is collected. This has to be poured back from time to time

into the funnel A, to pass through the tube again and again, until the exhaustion is completed. As the exhaustion is progressing, it will be noticed that the enclosed air between the mercury cylinders becomes less and less, until the lower part of *c d* presents the aspect of a continuous column of mercury, about 30 inches high. Towards this stage of the operation a considerable noise begins to be heard, similar to that of a shaken water-hammer, and common to all liquids shaken in a vacuum. The operation may be considered completed when the column of mercury does not enclose any air, and when a drop of mercury falls upon the top of this column without enclosing the slightest air-bubble. The height of this column now corresponds exactly with the height of the column of mercury in the barometer; or, what is the same, it represents a barometer, whose Toricellian vacuum is the receiver R.

The pump, Figs. 107, 108, of the pumping engine at Hartford, U.S., is noticed here on account of the peculiar action and arrangement of its valves and pistons. The engine is a double-acting condensing crank and beam engine, with a single cylinder 32·375 inches diameter, five feet stroke, with an adjustable cut-off. The injection water is taken from the well. There is a heavy fly-wheel of 22 feet diameter on the crank-shaft, and power is communicated by a pinion of twenty-seven teeth on the end of the shaft, gearing into a spur-wheel on either side, of eighty teeth, and on each spur-wheel shaft are two cams, each giving motion to a set of pumps by means of bell-cranks. Each set of pumps consists of two pistons or boxes in one chamber or cylinder, one above the other, see Figs. 107, 108; the piston-rod of the upper one being a tube, and the piston-rod of the lower box passing through it, the valves are butterfly-valves hinged in the middle; and each piston commences its stroke slowly, and increasing in a short space to its uniform velocity, and at the end decreasing for like distance till it stops. Thus while the lower box is rising, the upper is descending, the water passing up through the valves of the upper box; but just before the lower box has completed its up-stroke, the upper box has completed its down-stroke, and commences to rise, the lower decreasing in velocity and the upper increasing: and, *vice versâ*, during the rise of the upper box the lower one descends, and commences to rise in time to relieve the upper box at the end of its stroke. Thus the stroke of one box laps on to that of the other, and the absolute movement or stroke of 17·875 inches of each box may be considered 16·125 inches effective.

**AIR-SHAFT.** Fr., *Puits d'aérage, Buse d'aérage;* Ger., *Luftschacht, Wetterschacht;* Ital., *Pozzo di mina;* Span., *Pozo de ventilacion.*

An air-shaft is a passage for air into a mine, usually opened in a perpendicular direction, and meeting the *adits* to cause a free circulation of fresh air through the mine.

**AIR-STOVE.** Fr., *Calorifère à air chaud;* Ger., *Ofen zum heitzen mit warmer Luft;* Ital., *Calorifero* Span., *Calorífero de aire caliente.*

An air-stove is an enclosed fire-place so constructed as to admit a stream of air to pass round it or through it, and this impinging upon a heated surface is rarefied, carried upwards, and warms the apartment. See Ventilating and Warming.

**AIR-TRAP.** Fr., *Arrangement pour prévenir l'air impur des égouts et des ruyoles de se disperser dans les bâtiments;* Ger., *Eine Vorrichtung zum zurückhalten von fauler Luft in Cloaken;* Ital., *Valvola ad aria;* Span., *Aparato para impedir el escape de aire impuro de sumideros.*

An air-trap is a trap immersed in various ways in water, to prevent foul air rising from sewers or drains.

**AIR-VALVE.** Fr., *Soupape à air;* Ger., *Luftventil, Luftklappe;* Ital., *Valvola di sicurezza per il vuoto;* Span., *Válvula de aire.*

An air-valve is a safety-valve fixed at the top of a steam-boiler, and opening inwards to prevent rupture from the pressure of the atmosphere upon the sides of the boiler, should a vacuum occur within from the steam becoming condensed, or partially so.

**AIR-WAY.** Fr., *Passage pour l'air;* Ger., *Luftweg;* Ital., *Corso dell'aria;* Span., *Conducto de aire.*

A tubular passage for air flowing in pipes is termed an air-way.

**AJUTAGE.** Fr., *Ajutage, Ajutoir;* Ger., *Aufsatz (für Springbrunnen),* Ital., *Tubo d'aggiunta;* Span., *Tubo para regularizar la salida de aqua.*

A tube through which water is discharged is called an *ajutage*, as the *ajutage* of a fountain.

**ALGEBRAIC SIGNS.** Fr., *Signes algébriques;* Ger., *Algebraische Zeichen;* Ital., *Segni algebraici;* Span., *Signos Algebráicos.*

The sign +, termed *plus*, or more, is, like each of the other algebraic signs, a mere conventional mark; it indicates addition; thus, 18 + 19 = 37, that is, 18 added to 19 equal 37.

= being the sign put for, equal to; equal; or equals. $a + b = c$, or, in words, *a* added to *b* makes a sum equal to *c*.

+ is sometimes used to indicate that figures have been omitted from the end of a number, or that the number is approximately exact, as the square root of 5 is 2·2360679 +.

This little cross mark, when written diagonally like ×, stands for *multiplied by*; as, 15 × 8 = 120.

× also stands for *times* and *into*, as, $a \times b = ab$. Multiplication is also often indicated by placing a dot between the factors, or by writing the latter, when not numerals, one after another, without any sign; as, $a \times b \times c \times d = a \cdot b \cdot c \cdot d = abcd$; $1 \times 2 \times 3 \times 4 = 24 = 1\ 2\ 3\ 4$.

$a + a + a + a + a = 5$ times *a*, written 5*a*, must not be confounded with $a \times a \times a \times a \times a = a$ in the fifth power, written $a^5$. If $a = 2$, then in the first case $5a = 10$; and in the second $a^5 = 32$.

− Minus, less; which indicates subtraction; as, 7 − 3 = 4; that is, 7 less or diminished by 3 is equal to 4; if *p* be put for 7, *q* for 3, and *r* for 4, then $p - q = r$.

÷ or : stands for divided by; as, $x \div y$; that is, *x* divided by *y*. Now, to take a particular case, if $x = 24$, and $y = 3$, then $x \div y = 24 \div 3 = 8$. However, division is more generally indicated by writing the divisor under the dividend, with a line between them; as, $\frac{x}{y}$; that is, *x* divided by *y*. Supposing *x* to be put for 20, and *y* for 3, then $\frac{x}{y} = \frac{20}{3} = 6\frac{2}{3}$.

Small figures, 1, 2, 3, 4, &c., termed *indices*, are placed above and at the right hand of quantities to denote that they are to be raised to powers whose degree is indicated by the figure, as, $a$ or $a^1$, that is, the first power of $a$; $a^2$, the square or second power of $a$; $a^3$, the cube or third power of $a$, $a^4$, the fourth power of $a$, and the like. $4^3 = 4 \times 4 \times 4 = 64$. Small figures, in indicating powers, are often preceded by the negative sign (−), and thus show or indicate the reciprocal of the corresponding power, as, $a^{-1}$, $a^{-2}$, $a^{-3}$, $a^{-4}$, &c., are respectively equivalent to $\frac{1}{a^1}$, $\frac{1}{a^2}$, $\frac{1}{a^3}$, $\frac{1}{a^4}$, &c.

$\surd$, or $\surd\overline{\ }$ signifies root;—indicating, when used without a figure placed above it, the square root; as, $\surd 9 = 3$, $\surd 289 = 17$; $\surd 16\,a^2 = 4\,a$; and so on. This symbol is called the radical sign. To denote any other than the square root, a figure (called the *index*), expressing the degree of the required root, is placed above the sign; as, $\sqrt[3]{a}$, $\sqrt[4]{a}$, $\sqrt[9]{a}$, &c.; that is, the cube root, fourth root, ninth root, &c., of $a$. $\surd\overline{\ }$ is merely a modification of the letter $r$, which was used as an abbreviation of the Latin word *radix*, root. The root of a quantity is also denoted by a fractional index at the right-hand side of the quantity and above it, the denominator of the index expressing the degree of the root; as, $a^{\frac{1}{2}}$, $a^{\frac{1}{3}}$, $a^{\frac{1}{5}}$; that is, the square, cube, and fifth roots of $a$, respectively.

——— Vinculum,
( ) Parenthesis,
[ ], or { }, Brackets,

These signs indicate that the quantities to which they are appended, or which are enclosed by them, are to be taken together; as, $3\,(8 + 11) = 57$; that is, 8 is first added to 11, and then the parenthesis shows that the sum 19 has to be multiplied by 3. $3\,(8 \times 2 - 11) = 15$; that is, from twice 8 take 11, and multiply the remainder by 3. But $3\,(8 \times 2) - 11 = 37$, must not be taken for $3\,(8 \times 2 - 11)$. If $a = 2$ and $b = 3$, then, $(a + b)^2 = (2 + 3)^2 = 25 = \overline{a + b}^2$.

$$a \times [b + a^2\,(3\,b - a^2)] = 2\,[3 + 4\,(9 - 4)] = 46.$$

$$a \surd \{ (a + b) + a^2\,[3\,b - a^2] \} = 2 \surd \{ (2 + 3) + 4\,[9 - 4] \} = 10.$$

This last expression must not be confounded with the form

$$a \surd \{ (a + b + a^2)\,[3\,b - a^2] \} = 2 \surd \{ 9 \times 5 \} = 6 \surd 5 = 13{\cdot}4164078.$$

Is to, or the ratio of, is expressed by two dots, one placed over the other, as, (∶) between $a$ and $b$, $(a \div b)$, signifies $a$ is to $b$, or the ratio of $a$ to $b$. ∶ ∶ signifies as, or equals. This arrangement of dots is employed to indicate proportion; as, $a \div b :: c \div d$; that is, $a$ is to $b$ as $c$ is to $d$; or, the ratio of $a$ to $b$ equals the ratio of $c$ to $d$. In numbers, for example, if $a = 7$, $b = 3$, $c = 35$, then $d = 15$; for $7 \div 3 :: 35 \div 15$; as, $a \times d = b \times c$; or $\frac{a}{b} = \frac{c}{d}$.

☞ To understand the proper application of the symbols +; −; ×; ÷; $\surd$; $\surd\overline{\ }$; ( ); and ∶ ∶∶ ∶; is of much importance to the practical mechanic and engineer, especially if he has neglected the study of mathematics; for any person who understands common arithmetic, and how these symbols are applied, may determine the numerical value of any general formula in particular cases.

For example, the slip ($n$) of screw propellers, or paddle-wheels, is given by the formula

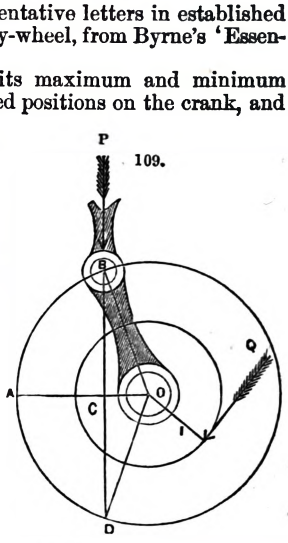
$$n = \frac{\surd g^3}{\surd g^3 + \surd d^3}$$

in which $g$ = the area of resistance, and $d$ = the acting area. Now, if $n$ be required when $g = 49$ square feet and $d = 225$ square feet, we have

$$n = \frac{\surd 49^3}{\surd 49^3 + \surd 225^3} = \frac{\surd 117649}{\surd 117649 + \surd 11390625} = \frac{343}{343 + 3375} = \frac{343}{3718} = {\cdot}09225.$$

To illustrate this method of substituting numbers for their representative letters in established formulæ, we select the following problems, respecting the crank and fly-wheel, from Byrne's 'Essential Elements of Practical Mechanics.'

*Problem.*—To find the position of the crank corresponding to its maximum and minimum velocity in a single-acting engine:—Let O B and O D be the required positions on the crank, and let P represent the constant pressure of the connecting-rod, supposed to act in a vertical line. Put Q = the constant resistance, acting at 1 foot from the axis of the fly-wheel, equivalent to the work of the engine.



109.

The motion will be accelerated from B to D. This acceleration will commence when the moving pressure is equal to the resisting pressure, and it will cease under the same condition. The former will correspond to the position of minimum, the latter to that of maximum velocity. Hence, at these two points the moment of P must be equal to the moment of Q, and the point D will be as much below the horizontal line A O as the point B is above it.

$$\therefore \quad P \times C\,O = Q \times 1. \qquad [1]$$

Again, by the equality of work, putting

$$r = O\,B,$$

Units of work by P in 1 revolution $= 2\,r\,P.$

" " Q " $= Q \times 2 \times 3{\cdot}1416.$

$$\therefore \quad 2\,r\,P = Q \times 2 \times 3{\cdot}1416. \qquad [2]$$

Dividing equation [1] by equation [2],

$$\frac{C\,O}{r} = \frac{1}{3{\cdot}1416} = {\cdot}31831$$

∴ From the table of natural sines ·31831 = cosine of 71° 27′; for $\frac{C\,O}{r}$ is the cosine of the angle B O C.

*Problem.*—To find the dimensions of the fly-wheel, such that its angular velocity may at no point differ from the mean velocity beyond a certain limit:—Let $d$ and $p$ be the maximum and minimum velocities of the wheel at the distance of 1 foot from the axis, W the weight of the wheel, and $k$ the distance of the centre of gyration from the axis.

Work of P from B to D = P × B D = P × $2r$ × sin 71° 27′ = $2r$ P × ·948.

Work of the constant pressure Q from D to B = $\frac{Q \times 2 \times 3{\cdot}1416 \times 142°54'}{360°}$ = $2r$ P × ·3968, by putting for Q × 2 × 3·1416 its value $2r$ P, found in the last problem.

Now the difference of these will give the *work* that goes to increase the speed of the wheel between the points B and D, that is, *work* going into the wheel between B and D =

$$2r \text{ P} \times {\cdot}948 - 2r \text{ P} \times {\cdot}3968 = r \text{ P} \times 1{\cdot}1022.$$

$$\text{Accumulated work at B} = \frac{p^2 k^2 \text{ W}}{2g}.$$

$$\text{Accumulated work at D} = \frac{d^2 k^2 \text{ W}}{2g}.$$

Hence the accumulated work gained from B to D = $\frac{k^2 \text{ W}}{2g}(d^2 - p^2)$, but this must be equal to the work before found;

$$\therefore \quad \frac{k^2 \text{ W}}{2g}(d^2 - p^2) = r \text{ P} \times 1{\cdot}1022 \qquad [3]$$

Let V be the mean velocity of the wheel at one foot from the axis, and let the extreme velocities $d$ and $p$ differ from this mean velocity by the $n$th part; then

$$d = \text{V} + \frac{\text{V}}{n} \text{ and } p = \text{V} - \frac{\text{V}}{n};$$

$$\therefore \quad d^2 - p^2 = \frac{4 \text{ V}^2}{n} \qquad [4]$$

Let N be the number of double strokes performed a minute, then

$$\text{V} = \frac{2 \times 3{\cdot}1416 \times \text{N}}{60} = {\cdot}10472 \times \text{N}; \qquad [5]$$

Let U be the work of the engine, then

$$\text{U} = 2r \text{ P N} \quad \therefore \quad r \text{P} = \frac{\text{U}}{2 \text{ N}} \qquad [6]$$

Substituting the values given in the equation [4], [5], [6], in equation [3], and reducing, $2g = 32\frac{1}{6}$

$$\text{W} = \frac{n \text{U}}{k^2 \text{ N}^3} \times \frac{32\frac{1}{6} \times 1{\cdot}1022}{4 \times ({\cdot}10472)^2}$$

$$\therefore \quad \text{W} = \frac{n \text{ U}}{k^2 \text{ N}^3} \times 808{\cdot}2 \qquad [7]$$

which is the expression for the weight of the fly-wheel in pounds.

If H be put for the horse-power of the engine, then U = 33000 H; substituting this in equation [7], and reducing to tons,

$$\text{W} = \frac{n \text{ H}}{k^2 \text{ N}^3} \times 11907 \qquad [8]$$

which is the expression in units of tons. Let R = the mean radius of the fly-wheel, $c$ = depth of the rim, then from a well-known property of the centre of gyration

$$k^2 = \text{R}^2 + \frac{c^2}{4};$$

substituting this in equation [8], then

$$\text{W} = \frac{n \text{ H}}{\left(\text{R}^2 + \frac{c^2}{4}\right) \text{N}^3} \times 11907.$$

Neglecting $\frac{c^2}{4}$ as being comparatively small, then

$$\text{W} = \frac{n \text{ H}}{\text{R}^2 \text{ N}^3} \times 11907. \qquad [9]$$

It may be observed that the weight of the wheel varies inversely as the cube of the number of strokes performed by the engine per minute.

If $a$ = the area of the section of the rim in square feet, and 450 lbs. be taken as the weight of a cubic foot of the metal, then W = 2 $\pi$ R $a \frac{450}{2240}$ tons nearly. Substituting in equation [9], and solving the resulting equation for R,

$$\text{then R} = \left(\frac{n \text{ H}}{\text{N}^3 a} \times \frac{11907 \times 2240}{2 \times 3{\cdot}1416 \times 450}\right)^{\frac{1}{2}}$$

$$\therefore \quad \frac{21}{\text{N}} \sqrt[3]{\frac{n \text{ H}}{a}} = \text{R},$$

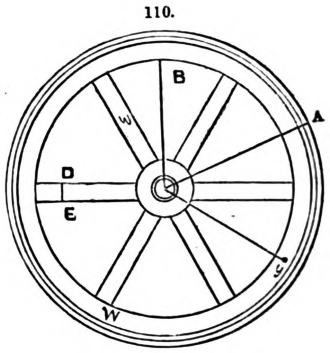
which is an expression for the mean radius of a cast-iron fly-wheel of a single-acting engine, when there are given the number of strokes of the piston, the horse-power, the area of the mean section of the rim, and the proportional variation from a mean velocity. Proceeding in the same way, for the double-acting engine, cosine B O A = 2 × ·31831,

$$\text{and R} = \frac{12}{\text{N}} \left(\frac{n \text{ H}}{a}\right)^{\frac{1}{2}}$$

In the fly-wheel B A W, Fig. 110, C A = R; C B = $r$, the outer and inner radius of the ring. W = weight of the ring in pounds; $w$ the weight of the arms, breadth of each, D E = $b$. If $y$ be the centre of gyration of the ring and arms, then, putting $y = C\,y$,

$$y = \sqrt{\frac{6\,W\,(R^2 \times r^2) + w\,(4\,r^2 \times b^2)}{12\,(W + w)}}.$$

110.




In practice, the centre of gyration, including the ring and arms, may be assumed at $y = r$ the length of the inner radius from the centre, C. Putting $a$ for the angular velocity or number of revolutions a minute, at the end of the time $t$ in which the fly-wheel would concentrate the same power as the steam engine, $t$ may be taken = 128 seconds; but when the work is irregular, $t$ may be taken as high as 170 seconds. Taking these average quantities, the weight of a fly-wheel for a given horse-power H will be

$$\text{Weight} = \frac{(11)^3 \times (10)^2 \times 128\,H}{a^2\,r^2}.$$

*Question.*—Required the weight of a fly-wheel when the engine is of 56 horse-power; the inner radius of the ring = 10 feet making 42 revolutions a minute?

$$\text{Weight} = \frac{133100 \times 128 \times 56}{42^2 \times 10^2} = 5409 \text{ lbs. nearly.}$$

We append other algebraic symbols, which have been employed by writers in treating of quantities that could be numerically expressed. Many of the following signs or symbols are obsolete, rare, or of far less importance to the mechanic or engineer than those which we have explained and illustrated.

$\perp$ Divided by; as, $a \perp b$; that is, $a$ divided by $b$; $6 \perp 3 = 6 \div 3 = 2$. [*Rare.*]

$>$ Is greater than; as, $a > b$; that is, $a$ is greater than $b$; $6 > 5$.

$\sqsubset$ Is greater than; — the same as $>$. [*Rare.*]

$<$ Is less than; as, $a < b$; that is, $a$ is less than $b$; $3 < 4$.

$\sqsupset$ Is less than; — the same as $<$. [*Rare.*]

$\not<$ Is not less than; — the contradictory of $<$; as, $a \not< b$; that is, $a$ is not less than $b$; or, $a$ may be equal to, or greater than, $b$, but cannot be less than it.

$\not>$ Is not greater than; — the contradictory of $>$; as, $a \not> b$; that is, $a$ is not greater than $b$; or, $a$ may be equal to, or less than, $b$, but cannot be greater than it.

$\eqsim$ Is equivalent to; — applied to magnitudes or quantities which are equal in area or volume, but are not of the same form, or capable of superposition; as, $a^2 \eqsim bc$; that is, the square whose side is $a$ is equal to the rectangle whose sides are $a$ and $b$. [*Rare.*]

$\shortmid$ Of the form of; as $a \shortmid (2n + 1)$; that is, the term $a$ is of the form $2n + 1$; $17 \shortmid (2 \times 8 + 1)$; that is, the odd number 17 is of the form $2 \times 8 + 1$. [*Rare.*]

$\nmid$ Is divisible by; as, $a \nmid b$; that is, $b$ is an exact factor of $a$; $8 \nmid 2$. [*Rare.*]

$\backsim$ The difference between; — used to indicate the difference between two quantities without designating which is the greater; as, $a \backsim b$; that is, the difference between $a$ and $b$.

$-:$ The difference between;—the same as $\backsim$. [*Rare.*]

$\propto$ Varies as; is proportional to; as, $a \propto b$; that is, $a$ varies as $b$, or is dependent for its value upon $b$.

$\therefore$ Geometrical proportion; as, $\therefore a : b :: c : d$; that is, the geometrical proportion $a : b :: c : d$ [*Rare.*]

$\dot{-}$ Minus; the arithmetical ratio of, } used to indicate arithmetical proportion; as, $a \dot{-} b$
$\dot{:}$ Equals; is equal to; } $\dot{:} c \dot{-} d$; that is, $a - b = c - d$. [*Rare.*]

$\infty$ Indefinitely great; infinite; infinity;—used to denote a quantity greater than any finite or assignable quantity.

0 Indefinitely small; infinitesimal;—used to denote a quantity less than any assignable quantity; also, as a numeral, naught; nothing; zero.

$\angle$ Angle; the angle; as, $\angle$ A B C = $\angle$ D E F; that is, the angle A B C is equal to the angle D E F;—less frequently written $>$ or $\backslash$.

$\frown$ or $\wedge$ The angle between; as, $ab$, or A $\wedge$ B; that is, the angle between the lines $a$ and $b$, or A and B, respectively.

By some geometers, the angle between two lines, as $a$ and $b$, is also indicated by placing one of the letters denoting the enclosing lines over the other; as, $\frac{a}{b}$; that is, the angle between the lines $a$ and $b$; sin. $\frac{a}{b}$; that is, the sine of the angle between the lines $a$ and $b$.

$\llcorner$ Right angle; the right angle: as, $\llcorner$ A B C; that is, the right angle A B C.

$\perp$ The perpendicular; perpendicular to; is perpendicular to: as, draw A B $\perp$ C D: that is, draw A B perpendicular to C D.

$\parallel$ Parallel; parallel to; is parallel to, as, A B $\parallel$ C D; that is, A B is parallel to C D.

$\underline{\vee}$ Equiangular; is equiangular to; as, A B C D $\underline{\vee}$ E F G H; that is, the figure A B C D is equiangular to the figure E F G H. [*Rare.*]

$\underline{\underline{\vartriangle}}$ Equilateral; is equilateral to; as, $\underline{\underline{\vartriangle}}$ D E F: that is, the figure A B C is equilateral to the figure D E F. [*Rare.*]

$\bigcirc$ Circle; circumference; 360°.

$\frown$ Arc of a circle; arc.

$\Delta$ Triangle; the triangle; as, $\Delta$ A B C = $\Delta$ D E F; that is, the triangle A B C is equal to the triangle D E F.

$\square$ Square; the square; as, $\square$ A B C D; that is, the square A B C D.

$\square$ Rectangle; the rectangle; as $\square$ A B C D = $\square$ E F G H; that is, the rectangle A B C D equals the rectangle E F G H.

$f$ or F; Function; function of; as $y=f(x)$; that is, $y$ is, or equals, a function of $x$.

Various other letters or signs are frequently used by mathematicians to indicate functions; as, $f$, $\phi$, $\phi'$, $\psi$, $\pi$, and the like. Some of these are used also without the parenthesis; as, $\phi x$, function of $x$.

$d$ Differential; as, $dx$; that is, the differential of $x$.

$\delta$ Variation; as, $\delta x$; that is, the variation of $x$.

$\Delta$ Finite difference.

D Differential co-efficient; derivative; — sometimes written also $d_{\cdot}$. The variable, with respect to which the differential co-efficient is taken, is indicated by writing the letter designating it at the right hand below; as, $D_t \phi$; that is, the differential co-efficient of $\phi$ with respect to $t$.

The letters $d$, $\delta$, $\Delta$, D, and sometimes others, are variously employed by different mathematicians, prefixed to quantities to denote that the differentials, variations, finite differences, or differential co-efficients of these quantities are to be taken; but the ordinary significations are those given above. An index is often placed at the right hand of $d$, to indicate the result of one or more repetitions of the process denoted by that sign; as, $d^2x$, $d^3x$, &c.; that is, the second, third, &c., differential of $x$, or the result of differentiating $x$ two, three, &c., times. This common device is clumsy and inadequate.

· Fluxion; differential; as $\dot{x}$; that is, in modern notation, $dx$. [*Obs.*]

$\int$ Integral; integral of; — indicating that the expression before which it is placed is to be integrated; as, $\int 2\,xdx = x^2$; that is, the integral of $2\,xdx$ is $x^2$. This sign is merely a modified form of S, which is itself the abbreviation of the Latin word *summa*, sum, the integral being the sum of the differentials. It is repeated to indicate that the operation of integration is to be performed twice, or three, or more times, as $\int\int$, $\int\int\int$, &c. For a number of times greater than three, an index is commonly written at the right hand above; as, $\int^m$, $xdx^m$; that is, the $m$th integral, or the result of $m$ integrations of $xdx^m$. The variable, with respect to which the integral is taken, is sometimes indicated by writing the letter designating it at the right hand below; as, $\int_x \phi$; that is, the integral of $\phi$ with respect to $x$.

$\int_b^a$ denotes that the integral is to be taken between the value $b$ of the variable and its value $a$. $\int^a$ denotes that the integral ends at the value $a$ of the variable, and $\int_b$ that it begins at the value $b$. These forms must not be confounded with the similar one indicating repeated integration, or with that indicating the integral with respect to a particular variable.

$\Sigma$ Sum; algebraic sum; — commonly used to indicate the sum or summation of finite differences, and in nearly the same manner as the symbol $\int$.

Residual.

( $\mathfrak{X}$ ) A symbol used in abbreviations of quantics whose terms have the same numerical co-efficients as a corresponding expression formed by involution; as $(a, b, c, d\,\mathfrak{X}\,x, y)^3$, which denotes the quantic $ax^3 + 3bx^2y + 3cxy^2 + dy^3$, the numerical co-efficients of which are the same as those obtained by expanding $(x+y)^3$.

( $\mathfrak{X}$ ) A symbol for a quantic which has no numerical co-efficients; as, $(a, b, c, d\,\mathfrak{X}\,x, y)^3$, which denotes the quantic $ax^3 + bx^2y + cxy^2 + dy^3$.

$\pi$ The number 3·14159265 + ; the ratio of the circumference of a circle to its diameter, of a semicircle to its radius, and of the area of a circle to the square of its radius. In a circle whose radius is unity, it is equal to the semi-circumference, and hence is used to designate an arc of 180°. In a circle whose diameter is unity, it is equal to the circumference, or an arc of 360°.

The ratio of the circumference of a circle to the diameter; — the same as $\pi$; a graphic modification of the letter C, for circumference.

The base of the hyperbolic system of logarithms; the same as $e$; a graphic modification of the letter B, for base.

M The modulus of a system of logarithms; — used especially for the modulus of the common system of logarithms, the base of which is 10. In this system it is equal to 0·4342944819+.

$g$ The force of gravity. Its value for any latitude is expressed by the formula $g = 32{\cdot}17076\,(1 - 0{\cdot}00259 \cos. 2\lambda)$, in which $\lambda$ is the latitude given, and 32·17076 (that is, 32·17076 feet per second) the value of $g$ at the latitude of 45°.

° Degrees; as 60°; that is, sixty degrees.

′ Minutes of arc; as, 30′; that is, thirty minutes.

″ Seconds of arc; as, 20″; that is, twenty seconds.

R° Radius of a circle in degrees of arc, equal to 57°·29578.

R′ Radius in minutes of arc, equal to 3437′·7468.

R″ Radius in seconds of arc, equal to 206264″·8.

′, ″, ‴, &c. Accents used to mark quantities of the same kind which are to be distinguished; as, $a'$, $a''$, $a'''$, &c., which are usually read $a$ prime, $a$ second, $a$ third, &c.; $a\,b'\,c'' + a'\,b''\,c + a''\,b\,c'$.

When the number of the accents would be greater than three, the corresponding Roman numerals are used instead of them; as, $a'$, $a''$, $a'''$, $a^{iv}$, $a^{v}$, $a^{vi}$, &c. The accents are often written below also; as, $a_{,}$, $a_{,,}$, $a_{,,,}$, $a_{iv}$, $a_{v}$, &c. Figures, and also letters, are sometimes used for the same purpose; as, $a^1$, $a^2$, $a^m$, $a^n$, $a_0$, $a_2$, $a_3$, $a_m$, $a_n$, and the like.

Indices or small figures are also often used to indicate the repetition of an operation; as, $d^1x$, $d^2x$, $d^4x$, &c., indicating that the operation of differentiation has been performed upon $x$ two, three, four, &c., times.

sin. $x$. The sine of $x$; that is, of the arc represented by $x$. In the same manner cos. $x$, tan. $x$,

cot. $x$, sec. $x$, cosec. $x$, versin. $x$, and co-vers. $x$, denote respectively the cosine, tangent, cotangent, secant, cosecant, versed sine, and co-versed sine of the arc represented by $x$.

$\sin.^{-1}x$. The arc whose sine is $x$. In the same manner $\cos.^{-1}x$, $\tan.^{-1}x$, $\cot.^{-1}x$, $\sec.^{-1}x$, $\operatorname{cosec}.^{-1}x$, $\operatorname{versin}.^{-1}x$, and $\text{co-vers}.^{-1}x$, are used to denote respectively the arc whose cosine, tangent, cotangent, secant, cosecant, versed sine, or co-versed sine is $x$.

This sign must not be confounded with the negative index designating the reciprocal of a quantity, which would be applied to a parenthesis inclosing one of these expressions; as, $(\sin. x)^{-1}$, which is equivalent to $\frac{1}{\sin. x}$.

Oliver Byrne, the inventor of the art and science of Dual Arithmetic, in developing which he employs in his works two new signs, an arrow (↓) and a comma (,); these signs (↓, ↑') do not interfere with those we have previously enumerated, as dual arithmetic essentially differs from arts previously known. Besides, those who examine dual arithmetic in all its bearings will find that a branch of greater importance has not been contributed to mathematical science; hence, how these new signs are applied may interest many.

↓ 6, 5, 3, 7, 9, 2, 3, 3, is a dual number of the ascending branch, composed of eight consecutive digits;

2 ↑ '0 '6 '7 '4 '3 '8 '1 '2 is a dual number of the descending branch, composed of the same number of dual digits; for the 2, to the left of the arrow, which in this case points up, is a coefficient;

↓ 6, 5, 3, 8, 0, '7 '6 '6 is a mixed dual number, the first four digits being of the ascending branch, and the last three of the descending. 2 ↓ '1 4, '2 2' 2, '3 '4 '5 is a dual number in the lowest terms, because the first digit does not exceed 3, and none of the other digits exceeds 5; all natural or common numbers may be readily reduced to dual numbers of the last form.

The natural number 1·869 = ↓ 6, 5, 3, 7, 9, 2, 3, 3,; 1·869 = 2 ↑ '0 '6 '7 '4 '3 '8 '1 '2; = ↓ 6, 5, 3, 8, 0, '7 '6 '6; = 2 ↓ '1 4, '2 '2 2, '3 '4 '5; and = a vast number of other dual numbers. The dual logarithm of $a$ is written ↓, ($a$), the dual logarithm of 2 or ↓, (2) = 69314718, which is a whole number.

↓, (1·869) = 62540354, and each dual number which represents 1·869 may be instantly reduced to the same dual logarithm, namely, 62540354. These observations apply to all numbers generally. Without the use of tables, in a variety of ways, and under different circumstances, Byrne in his works has shown by easy, independent, and direct processes, how any two of the three corresponding numbers

(Natural number); (Dual number); (Dual Logarithm);

may be found, the remaining one being given.

ALLOYS. Fr., *Alliages;* Ger., *Legirungen;* Ital., *Leghe;* Span., *Aleacion.*

Alloys, Metallic; *employed in the mechanical and useful arts.*

Every metallic alloy, as regards utility, may be considered a new species of metal, because the qualities of the constituents are in most cases not recognized again in the compound; the compound in such cases shows properties which do not belong to the simple metals, and which cannot be determined by theoretical speculations. By changing the proportions of tin to copper, we obtain bronze of different qualities, varying extremely in colour, hardness, and sound. A few per cent. of tin causes copper to be hard and more tenacious. The addition of a little lead causes brass to be more ductile, while a large addition makes it brittle. We shall not here enter fully into the peculiarities of alloys, as these peculiarities are given in our articles on particular metals employed in the mechanical and useful arts. Metallic elements do not at first sight appear to combine in certain ratios and form definite compounds; still it cannot be denied that some metals do; and we are justified, by the general law of affinity, in assuming that all metals combine chemically. We succeed always in melting various metals together, but we do not very often succeed in separating the excess of any one or more metals in the alloy, or the refractory nature of another. As a general rule, we may state that all the metals which form alkalies have a particular tendency to unite with those which form acids. *Potassium* combines readily with *antimony* and *arsenic*, more so than other metals. In considering the nature of protoxides in their chemical relations, we may successfully form a series in which the ability of metals to combine is represented.

This accounts for the peculiarities of the alloys of selenium, arsenic, antimony, and tellurium; which resemble very much the combinations of metal and sulphur, or phosphorus, or chlorine. All these substances form acids in their most simple combination with oxygen. Alloys and compounds of this kind are peculiarly inclined to be brittle and fusible. When two metals are near in the series of affinities for oxygen, they do not combine very readily; and they may often be separated by crystallization only, when their degree of fusibility is sufficiently distinct. This happens when both metals absorb the same, or nearly the same, quantity of oxygen in forming oxide. All chemical combinations liberate heat; silver and platinum, when melted together, produce a high temperature; so do zinc and copper. In most cases, we obtain a mere mechanical mixture of metals in an alloy; this is always characterized by forming distinct crystals with one metal, between which the other is visible. When an alloy is formed which contains equivalents, no such disconnected crystals are observed. An irregularly composed alloy is a mere mechanical mixture, like wax and fat, and never forms a uniform body of metal; it is of either a granulated or crystallized texture, the latter of which is not compact. Between the crystals of such an alloy, one of the metals is always found in a nearly pure condition. The alloy of iron and silver, in which the silver is mechanically enclosed between the crystals of iron, is an instance of these compounds.

Lead and tin combine in certain proportions, and whatever excess there may be of either metal, it is enclosed between the crystals of the alloy. The same is the case with zinc and tin, bismuth and tin—and, in fact, with all other metals. The number of definite compounds appears to be very large, and in all cases a metal is never obtained pure whenever another is present. In cooling a melted alloy, that composition which is most refractory crystallizes first; and that which is most fluid is compelled to occupy the spaces between the crystals of the most refractory. Thus, copper

and tin are very fusible; but in cooling, copper-tin crystallizes first, and tin-copper last—which latter occupies the spaces between the first. Iron and arsenic are very fusible, but in cooling, iron-arsenic crystallizes first, and arsenic-iron last; the surface of the cooled mass shows a perfect network of bright lines, in regular forms. In all these compounds the first crystallized metal, or alloy, contains some of the latter, and the latter some of the first.

When a bar of cold lead is held in mercury, the first absorbs some of the latter throughout its body; the pores of the lead are filled with mercury—but the mercury in this case contains lead, as well as the lead mercury. When iron is gently heated imbedded in carbon, as is the case in making blistered steel, the carbon penetrates the very heart of the iron-rods; but no iron is imparted to the carbon, because its particles are not movable. By these and similar means the pores of a refractory, solid metal, may be filled with another metal, provided the atoms of the latter are movable. Lead does not readily combine with iron, but if we heat wrought-iron turnings in melted lead, the solid iron will absorb lead. Gray cast-iron will not absorb lead, because its pores are filled with carbon. Borings of cast-iron absorb arsenic readily, when imbedded in arsenious acid and heated; but wrought-iron does not absorb arsenic by these means until carbon is brought into contact with these substances. In properly applying these rules, we may form alloys of the most heterogeneous metals, and in regular proportions.

It is extremely difficult to form a definite compound of zinc and copper, or tin and copper; but if we take either the oxides of all these metals, or the oxide of any one, and the metal in small particles, and imbed the whole in carbon—heating it so as not to melt it, although bringing it near its melting point—and then apply the heat gradually and slowly, we are enabled to form definite compounds, which may be melted by a heat which does not evaporate either the one or the other metal. We shall point out the formation of alloys by metals in other articles, but we wish to draw the attention to these facts, because it is often very difficult to form an alloy of a definite composition. Yet as these alloys are the most valuable, we refer to the above mode of forming them.

*Fusibility of Alloys.*—Alloys are more fusible than the mean temperature at which the metals melt singly would indicate. This is a very important law in our investigations, and affords, when properly applied, the most valuable results. When tin melts at 500°, and pure copper at 2500°, equal parts of copper and tin do not melt at $\frac{2500 + 500}{2} = 1500°$, but at a lower heat. Platinum, and also chromium, are infusible in our furnaces, but may be made very fusible by the addition of arsenic. Pure iron is extremely refractory, but when combined with arsenic and phosphorus, it may be melted in a cast-iron pot, without adhering to it. Thus, when an alloy of two metals is fusible at a lower heat than the mean of the two, a composition of three metals is still more fusible than their various degrees of melting indicate; and by multiplying the number of component parts, a low degree of fusibility of any metal may be obtained. If the composition is according to the laws of chemical affinity, the melting point is lowest. In all cases of practice we must reflect on the application of the metal before we form an alloy, the object of which is to facilitate the smelting operation. If phosphorus causes iron to be very fusible, and coal, flux, and labour, may be saved in smelting bog ores which contain phosphorus, the first inquiry must be whether the cold-short iron thus obtained is of any value.

Arsenic and zinc cause lead and silver ores to be easily melted, but the loss in silver by this operation is so great as to make it desirable to remove these volatile metals before any smelting is entered upon. We may flux copper by arsenic, but not by lead, because we can remove the first in refining, but not the latter sufficiently to form a good quality of copper for sheets. Arsenic, lead, or zinc may be in iron which is destined for wrought-iron, for these metals are easily removed in the refining process. It is always more safe in smelting gold ores to have lead, copper, or silver present, and if possible all of them; for gold is very volatile and extremely divisible, hence much of it may be lost when no other metals which act by their quantity are present. Lead fuses at 600°, tin at 500°, and bismuth at 400°; but a composition of the three may be made which melts at 212°, a heat far below the most fusible of the ingredients. This shows how great the advantages are which may be obtained by forming alloys in the smelting furnaces. It is the degree of fusibility of the slags and that of the metals which determines the expenses of smelting. The number of alloys is infinite. We cannot establish tables of fusibility *a priori*; these must be determined by practice. In all smelting operations it is necessary to find the most profitable conditions by experiment.

If an alloy is more fusible than a single metal, it follows that, when one or the other constituent is removed, the fusibilty of the metal is impaired. An alloy of lead and arsenic is more fusible than pure lead; but when the alloy is exposed to heat for a long time, arsenic will evaporate; and as it was the cause of fluidity, the lead will not be so fusible after losing its flux. Iron is made fusible by the presence of carbon or other substances, but when these are removed it is very refractory, and can hardly be melted. Upon this principle the formation of wrought-iron is founded; and in applying it to other metals there is no doubt but similar results are obtained. Tin is refined by oxidizing or evaporating sulphur, arsenic, and other matter; this causes the tin to be less fusible, but more tenacious. When zinc is melted in an iron pot, and exposed to the air, it forms dross on its surface, like other metals; its fluidity is consequently diminished, but its malleability is improved. A layer of carbon, or, what is still better, a layer of common salt, or bone ashes, prevents such phenomena with zinc and similar metals.

*Specific Gravity.*—When metals are melted together and form an alloy, there is produced a remarkable change in their specific gravity; which is sometimes greater and at other times less than the mean. A condensation of volume is manifested in melting together zinc and gold; the specific gravity of the compound is greater than the mean of the constituents; gold also and silver condense, or gold with lead or bismuth; silver combined with copper, lead, tin, bismuth, and zinc or antimony shrinks; also copper with tin, zinc, or antimony; lead with zinc, bismuth, or antimony;

mercury with tin or lead, bismuth or antimony. An expansion takes place when gold is melted with copper, iron, or tin; also platinum with copper; iron with antimony, bismuth, or tin; also copper and lead; tin and zinc, lead or antimony; zinc and antimony, and mercury with bismuth. In consequence of this contraction or expansion we are justified in assuming a similar change in the aggregate form.

*The hardness* of alloys is generally greater than may be inferred from the nature of the constituents; still there are exceptions to this rule. Silver or arsenic renders iron hard; but these metals are soft by themselves: copper and tin, two very soft metals, may be made extremely hard by melting them together in certain proportions. Hard zinc and copper make soft brass, and a compound of lead and iron is extremely soft. Antimony causes all metals to become hard; iron, with a little antimony, cuts glass very readily, but is very brittle.

The ductility of alloys is in some cases greater than the elements indicate; that of lead and zinc is very tenacious. In most instances the alloy is more brittle than the original metals. Lead and antimony is very brittle. Two or more brittle metals melted together are always brittle. A compound of lead and gold is very brittle. There is no precise limit at which we know when brittle or malleable alloys are formed; it is necessary to find this by practice; but there are strong indications that the alloy of an equivalent composition is always harder than a mere mechanical mixture of metals. Any alloy, when slowly heated and gradually cooled—annealed—is softer than a compound which is suddenly chilled. In annealing, the various elements which are in combination endeavour to separate. Heat here, as everywhere, weakens affinity. This causes a finely crystallized, or a granulated fracture; the component particles endeavour to assume a round form. When a hot alloy is suddenly chilled, the particles of which it is composed contract suddenly, and form a close, compact body; at least the ultimate crystals are condensed into the smallest space, which causes them to be hard. This is most strikingly exemplified in some kinds of iron.

Any kind of iron in market may be considered an alloy; there is no such thing as pure iron. Some wrought-iron contains much foreign matter, and still is soft as lead, and fibrous. If such iron is heated to a certain degree, that is, beyond the degree at which it has been manufactured, it becomes cast-iron, is brittle, and when suddenly chilled becomes hard, similar to steel. Such iron may be annealed and softened like steel, or any other alloy. The hardness of an alloy is therefore less dependent upon its composition than upon the arrangement and form of the ultimate particles.

*Oxidation.*—Alloys oxidize more rapidly than single metals; to this rule there are, however, remarkable exceptions. Hardened or crystallized metal oxidizes more rapidly than tempered or annealed metal, which is most strikingly exemplified in iron and steel. It appears that metals expand on being suddenly chilled. The spaces thus formed between the crystals are fissures into which oxygen may penetrate with facility; and as the crystallized form of the particles affords much surface for combination, an oxidation is readily effected. An alloy of antimony and iron, two metals which are remarkable for crystallization, oxidizes very readily; such an alloy may be ignited by mere filing, particularly when it is a little heated previously to that operation. Chrome and lead act in a similar manner. Antimony and potassium burn spontaneously, and if a little warm, with explosion. An alloy of tin and lead—soft solder—burns with a vividness equal to carbon, and if some zinc is present only a low heat is required to ignite the mixture.

An amalgam of potassium and mercury is so sensitive to oxygen that the mercury is oxidized to a high degree. In many cases, and under peculiar arrangements, the oxidation is carried to the highest degree: we have seen that in roasting sulphurets, phosphurets, and other compounds, the metal is always oxidized to the highest degree. The same cause acts in both cases. When two or more metals are melted together, there is a perfect penetration of the one by the other. In heating the mass, the tendency to separation is augmented, and as the ultimate particles of one metal cannot congregate and form large particles, they are exposed to the action of oxygen in their minutest form, and consequently will combine with the largest quantity of oxygen. If one kind of metal is more oxidizable than the other, or if the mass is porous, the oxidation goes on, not only faster, but must proceed to the highest degree, because the atoms of metal may be attacked by oxygen on all sides. While some alloys are easily oxidized, others resist that influence more than pure metals.

Pure iron is very easily oxidized, and often throughout, when in heavy masses. It has been found that a lot of bloom four inches thick, of puddled iron, was oxi-lized in a *reheating furnace* by giving merely a drawing heat to such a degree, that when drawn out between rollers into bars, these were found to be converted partly into magnetic and partly into protoxide of iron. This iron was puddled under the influence of a cinder highly charged with chlorides. Metals are porous, and easily penetrated by other matter. Thus, water enters successfully into the body of cast or wrought iron; and if a metal is present, or any other substance which decomposes water, the iron is easily oxidized. We find, when carbon is present, that oxygen has little effect on iron; but when any of those substances which form acids, such as arsenic, antimony, or sulphur, are combined with the metal, it is an easy prey to oxygen. An alloy of chromium and iron resists oxygen as well as gold; and phosphuret of copper is not so easily affected as pure copper. Bronze will resist the influence of oxygen much longer than pure copper.

It appears that the degree of affinity has less influence on the oxidation of metals than the aggregate form of their particles and the strength of their union. Hardened steel oxidizes more readily than annealed steel, and chilled cast-iron more so than gray cast-iron. Hammered or rolled lead is less penetrable by mercury than cast lead. German silver, which is composed of oxidizable metals, is little affected by oxygen, and less so when rolled than when cast. Copper has a strong affinity for sulphur, and is more readily attacked by it than iron, when finely divided; yet, when in a compact body, it will resist that substance far more successfully than iron. Some kinds of brass are remarkably liable to oxidation, while others resist it more effectually. A

surface of metal, which is highly polished, and particularly when polished by rubbing it with a hard substance, is far less subject to oxidation than a rough surface. If it is desirable to resist oxidation, or in fact the influence of any other matter upon metal, those alloys must be formed which have naturally little affinity for that particular substance, and which, in the mean time, form the most intimate union, so that the penetration of foreign matter into the body of the metal is prevented. It is not the compactness of zinc or lead which prevents their oxidation in the atmosphere; it is the cover of oxide, which forms a close body, and prevents the further penetration of oxygen. We may assert that the density of gold and silver has as much influence in preventing their oxidation as their want of affinity for oxygen. Affinity between the metals of an alloy has, in consequence of an intimate union, a large share in preventing oxidation.

Iron is easily oxidized, but it is less subject to that influence when combined with phosphorus, than when alloyed with silver or gold, particularly the former: this is chiefly because silver has but little affinity for it, and is thus excluded from its crystals, and forms a layer between them. There is a separation; oxygen finds access, and a rapid action of it is the consequence. Carbon protects iron successfully, not in consequence of its greater or less affinity for oxygen or iron, but chiefly on account of its form. Carbon is exstic, and will fill the spaces between the particles of metal. When gray or white cast-iron contains five or six per cent. of carbon, the latter will form a body, when liberated, which cannot be condensed into the same space again by any mechanical means; and even in the form graphite it occupies nearly the space of the iron. Still, cast-iron is porous. All substances foreign to iron, which are contained in the finest kind of cast steel, cannot, when liberated, be condensed into the same space which they occupied in the steel; and such steel, when glass hard, is very porous, there is not even cohesion between its particles; it is brittle.

*Component Elements of Metallic Alloys in General Use.*

**Yellow brass**, 2 parts copper, 1 zinc. **Rolled brass**, 32 parts copper, 10 zinc 1·5 tin.
**Brass—casting, common**, 20 parts copper, 1·25 zinc, 2·5 tin.
**Hard brass, for casting**, 25 parts copper, 2 zinc, 4·5 tin.
**Gun-metal**, 8 parts copper, 1 tin.
**Copper flanges for pipes**, 9 parts copper, 1 zinc, 0·26 tin.
**Brass that bears soldering well**, 2 parts copper, 0·75 zinc.
**Muntz's metal**, which can be rolled and worked at red heat, 6 parts copper, 4 zinc.
**Statuary metal**, 91·4 parts copper, 5·53 zinc, 1·7 tin, 1·37 lead.
**German silver**, 20 parts copper, 15·8 nickel, 12·7 zinc, 1·3 iron.
**Frick's German silver**, 53·39 parts copper, 17·4 nickel, 13 zinc.
**Metal for medals**, 100 parts copper, 8 zinc. **Pinchback**, 5 parts copper, 1 zinc.
**Chinese silver**, 65·2 parts copper, 19·5 zinc, 13 nickel, 2·5 silver, and 12 cobalt of iron
**Britannia metal**, 1 part zinc, 1 antimony / When fused add 1 antimony, 1 bismuth } 1 zinc, 2 antimony, 1 bismuth.
*Aich's metal*, an alloy of iron, copper, and zinc, called also sterro metal.
**Babbit's anti-atrition metal**, 25 parts tin, 2 antimony, 0·5 copper.
**Bell-metal for large bells**, 3 parts copper, 1 tin; for small bells, 4 parts copper, 1 tin.
**Newton's fusible alloy**, 3 parts bismuth, 5 lead, 3 tin; melts at 212°.
**Rose's fusible alloy**, 2 parts bismuth, 1 lead, 1 tin; melts at 201°.
**Very fusible alloy**, 5 parts bismuth, 3 lead, 2 tin; melts at 199°.

*Solders.*—Tin solder, coarse, 1 part tin, 3 lead; ordinary tin solder, 2 tin, 1 lead; melts at 500° and 360° respectively. Soft spelter-solder, for common brass-work, 1 part copper, 1 zinc. Hard spelter-solder for iron, 2 parts copper, 1 zinc. Solder for steel, 19 parts silver, 3 copper, 1 zinc. Solder for fine brass-work, 1 part silver, 8 copper, 8 zinc. Pewterers' soft solder, 2 parts bismuth, 4 lead, 3 tin. Pewterers' common solder, 1 part bismuth, 1 lead, 2 tin. Gold solder, 24 parts gold, 2 silver, 1 copper. Hard silver-solder, 4 parts silver, 1 copper. Soft silver-solder, 2 parts silver, 1 brass-wire.

*Fusibility of Alloys.*

| Parts Tin. | Parts Lead. | Parts Bismuth. | Melts at | Parts Tin. | Parts Lead. | Parts Bismuth. | Melts at |
|---|---|---|---|---|---|---|---|
| | | | ° | | | | ° |
| 2 | 3 | 5 | 199 | 4 | 5 | 4 | 266 |
| 1 | 1 | 2 | 200·75 | 4 | 6 | 4 | 270 |
| 3 | 5 | 8 | 202 | 1 | .. | 1 | 286 |
| 3 | 3 | 8 | 202 | 45·3 | .. | 54·6 | 325 |
| 3 | 6 | 8 | 208 | 3 | 2 | .. | 333 |
| 3 | 8 | 8 | 226 | 2 | 1 | .. | 360 |
| 2 | 4 | 4 | 243 | 8 | .. | 1 | 392 |
| 6 | 1 | 5 | 245 | 1 | 3 | .. | 500 |
| 1 | 1 | 1 | 254 | | | | |

Tin melts at 442°. Bismuth at 480°. Lead at 600°.

*Specific Heat of Various Substances.*

| | | | | | |
|---|---|---|---|---|---|
| Water .. .. .. | 1·0000 | Glass .. .. .. | ·1770 | Silver .. .. .. | ·0557 |
| Hydrogen .. .. | 3·2936 | Iron .. .. .. | ·1098 | Tin .. .. .. | ·0514 |
| Steam .. .. .. | ·8470 | Copper .. .. .. | ·0949 | Platinum .. .. | ·0355 |
| Nitrogen .. .. | ·2754 | Phosphorus .. .. | ·1880 | Mercury .. .. | ·0330 |
| Air .. .. .. | ·2669 | Zinc .. .. .. | ·0927 | Lead .. .. .. | ·0310 |
| Oxygen .. .. | ·2361 | Alcohol .. .. .. | ·0700 | Bismuth .. .. | ·0288 |
| Carbonic Acid .. | ·2210 | Ether .. .. .. | ·0600 | Carbon .. .. | ·2570 |

*Ductility and Malleability of Metals.*

| Ductile and Malleable Metals in alphabetical order. | Brittle Metals in alphabetical order. | Metals in order of their Wire-drawing Ductility. | Metals in order of their Laminable Ductility. |
|---|---|---|---|
| Cadmium. | Antimony. | Gold. | Gold. |
| Copper. | Arsenic. | Silver. | Silver. |
| Gold. | Bismuth. | Platinum. | Copper. |
| Iron. | Cerium. | Iron. | Tin. |
| Iridium. | Chromium. | Copper. | Platinum. |
| Lead. | Cobalt. | Zinc. | Lead. |
| Magnesium. | Columbium. | Tin. | Zinc. |
| Mercury. | Iridium. | Lead. | Iron. |
| Nickel. | Manganese. | Nickel. | Nickel. |
| Osmium. | Molybdenum. | Palladium. | Palladium. |
| Palladium. | Osmium. | Cadmium. | Cadmium. |
| Platinum. | Rhodium. | | |
| Potassium. | Tellurium. | | |
| Silver. | Titanium. | | |
| Sodium. | Tungsten. | | |
| Tin. | Uranium. | | |
| Zinc. | | | |

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ALLUVIAL DEPOSITS. Fr., *Débris d'alluvion*; Ger., *Anschwemmungen*; Ital., *Strati d'alluvione*; Span., *Depósitos de aluvion.*

Alluvial deposits are those deposits of earth, sand, gravel, and other transported matter, made by rivers, floods, and other causes upon land, not permanently submerged beneath the waters of lakes or seas.

ALUMINUM. Fr., *Aluminium*; Ger., *Aluminium*; Ital., *Aluminio*; Span., *Aluminio.*

Aluminum is the *metallic base* of alumina. This metal is white, but with a bluish tinge, and is remarkable for its resistance to oxidation, and for its lightness, having a *specific gravity* of only about 2·6. The electrical indifference of this metal is most striking, and its effects upon other metals have been extensively investigated. Aluminum is produced from alumina by a peculiar smelting process. When pure alumina, the oxide of this metal, is mixed with finely pulverized carbon, and exposed in a porcelain tube to a red heat, and, in the same time, chlorine is conducted over it, a dry chloride of aluminum is formed, accompanied by a vivid combustion. When this substance is placed in a porcelain crucible, upon whose bottom some pieces of pure potassium are deposited, and the crucible is well covered and luted, and then gently heated over a spirit-lamp, a reduction of the alumina is performed by the potassium, with the production of a high heat at the moment when these two metals decompose each other. Here is a reduction of one metal by the other, as we have seen it performed in reducing sulphurets.

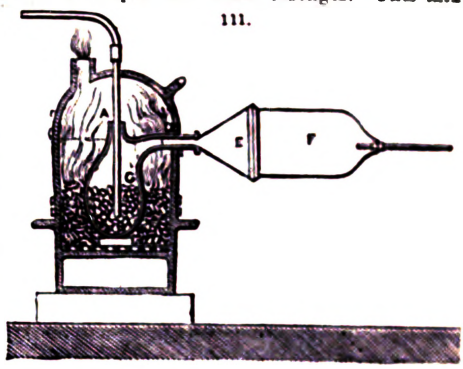
This operation is, therefore, not confined to sulphur, oxygen, phosphorus, and similar substances; it applies to all metals and their combinations, and it requires nothing but a proper selection of the decomposing substance, and the conditions under which it may be performed. The aluminum thus obtained is similar to the alkaline metals; it is very refractory, and does not melt at the heat of melted cast-iron; it is hard, tenacious, and not oxidized at common temperatures, but requires a high red-heat for oxidation. This metal has been observed, alloyed with iron, in Indian steel, and it has been said that the excellent qualities of that steel are owing to its presence. Experiments which have been made with this view have shown that iron combined with aluminum is remarkably strong. In endeavouring to combine aluminum with other metal, we are in the same predicament as with the alkaline metals; silex is reduced before alumina is affected by carbon; and if any advantages are to be derived from an alloy of this kind, silex ought not to be present at its formation. The process used at the Talyndre Works for the manufacture of alumina has been described in the *Revue Universelle.*

At the Talyndre Works they are working a very valuable ore, furnishing pure alumina by two very simple operations, which now renders the preparations of aluminum an actual metallurgical operation in the Ollionelles, near Toulon. Its average composition is—alumina, 60 per cent.; oxide of iron, 25; silica, 3, and water 12 per cent. = 100. After being pulverized under an edge-runner, it is mixed with soda, and heated in a reverberatory furnace. The mass, although not even agglutinating, becomes changed into an aluminate of soda, and a double silicate of soda and alumina is obtained, mixed with oxide of iron, silica, and a little of the alumina which has not reacted. The aluminate of soda is dissolved out with water (the impurities remaining undissolved), and thrown in fine streams through a current of carbonic acid, by which means alumina is thrown down, and carbonate

of soda remains. The precipitated alumina is separated by decantation, and washed with warm water to remove the last traces of soda. In practice no soda is lost, except a small portion converted into silicates, the remainder being recovered by evaporation. The alumina is completely dried, and is ready for final treatment. The manufacture of the sodium has been but little modified. The final reaction which yields the aluminum is effected in a reverberatory furnace. To the double chloride of aluminum and sodium is added about 5 per cent. of sodium; and lastly, cryolite as a flux. By this means the metallic aluminum is economically and speedily produced.

*To prepare the Chloride of Aluminum.*—A mixture is made of alumina and charcoal, and the whole made into paste with some oil, so that it may be shaped into small lozenges. This mixture is placed in a well-made fire-clay retort, Fig. 111; as soon as the retort is brought to a dark red heat, a current of dry chlorine gas is passed into the retort, whereby at first water is expelled from the apparatus, and soon after vapours of chloride of aluminum are produced in abundance. The vapours of the chloride of aluminum are collected in the bell-jar F, which is so narrow that it soon gets sufficiently hot to cause the fusion of the chloride of aluminum, which is hence obtained in a concrete mass. The bell-jar, used as a condenser, is fixed to the neck of the retort A by means of a funnel E, luted on with fire-clay mixed with chopped cow-hair; the tube at the other end of the condenser serves to carry off the carbonic oxide gas, which must be ignited after the air has been entirely expelled from the apparatus. In order to prevent the neck of the retort A from chocking up, it should not project out of the furnace more than five or six inches. With the apparatus just described, 12 lbs. of chloride of aluminum may be prepared daily. The aluminum is obtained from the salt known as ammonia alum, a double salt of alumina and ammonia as bases, both combined with sulphuric acid; it so happens that, at higher temperatures, both the ammonia and sulphuric acid are volatile, and hence alumina is left in a state nearly pure, if the salt previously used be pure.

111.




**ALUMINUM BRONZE.** Fr., *Bronze d'Aluminium;* Ger., *Aluminium bronze;* Ital., *Bronzo d'alluminio;* Span., *Bronce de aluminio.*

Aluminum bronze is an alloy of copper and aluminum mixed in different proportions. This alloy has a golden hue, and is extensively used in the manufacture of cheap jewellery. One hundred parts copper and ten parts aluminum, measured by weighing, when combined forms a very durable alloy, which may be forged and worked in the same manner as copper. This alloy, of 100 c. to 10 al., takes a fine polish by being burnished, and is the same colour as pale gold; 100 c. and 5 al. forms an alloy, which takes a fine polish by burnishing; it resembles pure gold in colour, but is less durable than the former alloy of 100 c. and 10 al. Farmer's Aluminum Bronze is a mixture in which the copper may vary from 65 to 80 per cent. of the whole, and the zinc, or other light-coloured metals, from 35 to 20 per cent. of the whole; the aluminum being from $\frac{1}{10}$ths to $\frac{1}{100}$ths of the whole quantity of the light-coloured metals used.

**AMALGAM.** Fr., *Amalgame;* Ger., *Amalgam;* Ital., *Amalgama;* Span., *Amalgama.*

An amalgam is a compound of mercury with some other metal, or a native compound of mercury and silver. See Amalgamating Machine. Gold and Silver.

Amalgamating Machine, *in silver mining.*

**AMALGAMATING MACHINE.** Fr., *Machine à amalgamer;* Ger., *Amalgamir Maschine;* Ital., *Macchina per amalgamare;* Span., *Máquina para amalgamar.*

Varney's amalgamating pan is shown in Figs. 112, 113, 114, 115, 116, 117, 118, 119, 120. Fig. 112 is a vertical section of this amalgamator; Fig. 113, a plan of the parts beneath pan; Fig. 114, elevation of the amalgamator complete; Fig. 115, view of interior of amalgamator; Fig. 116, view of one-half the lower dies with wood in slots; Fig. 117, view of under-side of one-half of muller with shoes attached; Figs. 118 and 119 stand for gear on vertical shaft; and Fig. 120, pillow-block for the driving-shaft.

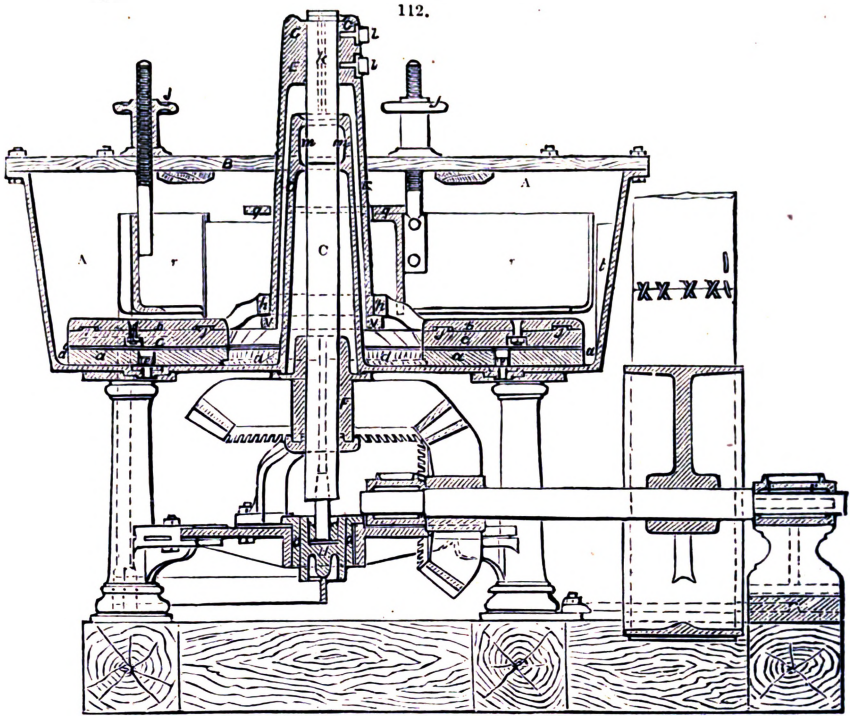
The body of the amalgamator consists of a pan or tub A, Figs. 112 and 114, with cover B, through which is an opening for the introduction of the pulp to be ground and amalgamated. The pan is supported on suitable framework, shown in Fig. 113. From the centre of the pan, and extending from its bottom, to which it is cast, some distance above the cover stands the vertical tube D, through the interior of which is a hole passing vertically through the pan, in order that the shaft C may work through it. On the bottom of the pan, and secured to it by bolts *c*, is fixed the lower muller *a*, consisting of a circular iron-plate having a round hole *d* in its centre, considerably larger than the base of the tube D. This die may, if desired, be made in sections.

That portion of the hole through the muller not occupied by the tube D, is so filled with wood, as to present a plain surface from the tube to the circumference of the muller. The diameter of this muller is somewhat less than that of the interior of the pan, by which means a space *a'* is left to be filled with quicksilver. Above the lower muller is the upper one *b*, of like general form and size, having twelve shoes *c*, the form and relative positions of which will be understood by supposing a plate of the diameter and thickness of the lower muller attached to the under-side of the upper one, and sawn into twelve equal parts on lines drawn from the circumference of the plate to the outside of the tube D. The saw must also be supposed to be held inclined at an angle of about forty-five degrees, thus forming radial grooves from the inner to the outer opening.

Each shoe is fastened to the muller by a bolt, or a wrought-iron rivet, cast into the shoe and

riveted into a counter-sink on the upper side of the muller, as shown at *f*, Fig. 112; the bosses and recesses *j*, keep the die in its place. In the lower muller are radial slots, similar to those in the upper one. These slots may be either inclined laterally or be made vertical. The slots in the lower muller are filled with wood, so as to grind on its end, in order that it may be kept slightly worn, in advance of the wear of the die; thus furnishing a cavity for the admission of pulp between the surfaces, by which the grinding capacity of the machine is greatly increased.

112.



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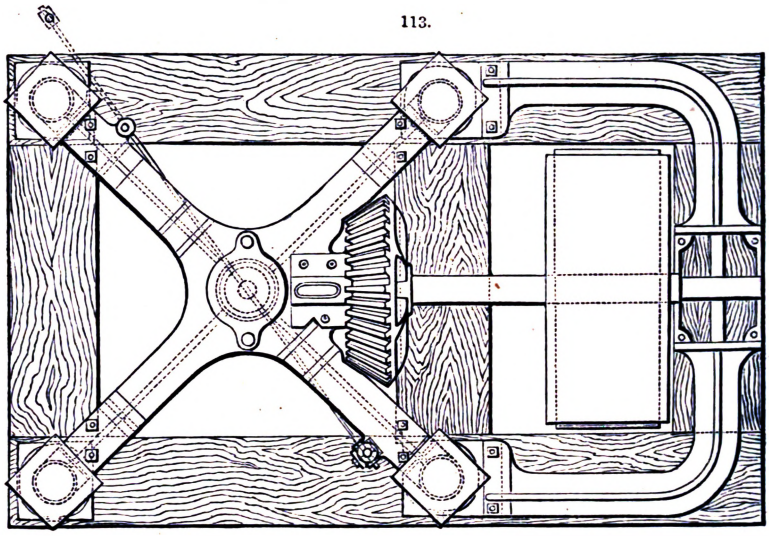
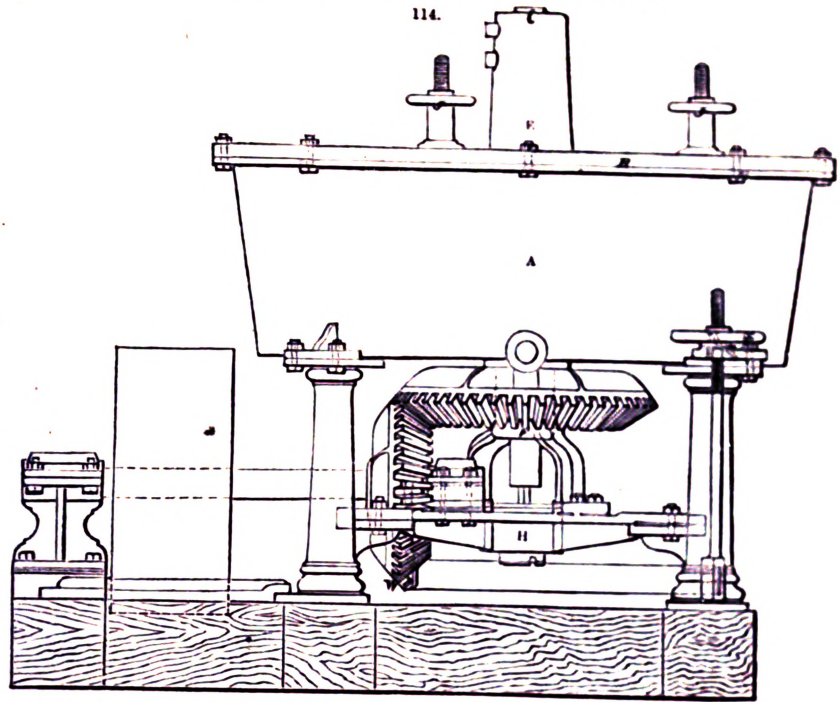


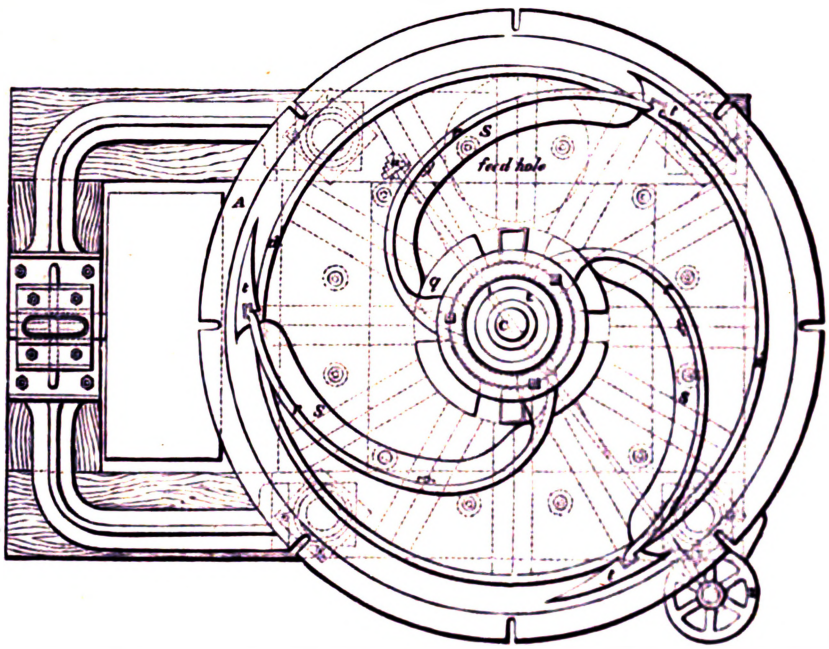
Over and around the tube D, but not in contact with it, is placed the larger tube E, exactly perpendicular to the lower face of the upper muller, and having around its lower extremity the flange V, upon which rests the ring *h*, which is cast with, and forms a part of, the upper muller. This is connected with the muller by means of six curved arms *i*, two pairs of which are much nearer together than the others, and the space between them is filled by a projection from the periphery of the flange V, for the purpose of carrying with it the upper muller when the flange makes a revolution. To the shaft C is fastened the large tube E by the feather *k*, and set-screws *l* in the hub G. The shaft C passes through a *Babbit's metal bearing* at *m*, and through the boss F of the driving-wheel, in which is a feather sliding vertically in the shaft. The shaft is stepped, by the ordinary method, into the vertical sliding-box H, which is itself held in the laterally adjustable box O.

The step-box rests upon an iron bar, one end of which is supported by a screw bolt *w*, Fig. 115, and the other is held by a bolt and hand-wheel *x*, Figs. 114 and 115, by which it can be either raised or lowered; raising or lowering the upper muller at the same time.

114.




115

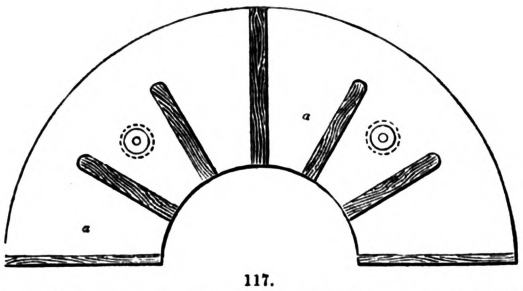



Within the body of the pan are suspended three curved plates *r*, Figs. 112 and 115, extending from near the surface of the upper muller upwards, and stretching in length from the inner side of the pan around to a point near the outside of the large boss, opposite that from which they started.

The lower edges of the curved plates are bent inwards, as shown at *s*, Fig. 115, forming flanges. The inner ends of the curved plates are secured rigidly to the ring *q*, of sufficient diameter to surround and clear the tube E; the whole being suspended by a rod attached to each plate, passing through the cover and hand-wheels J, by which it may be adjusted. The outer ends of the curved

plates slide vertically in grooves in the projections *t*, cast upon the inner side of the pan. The operation of this apparatus is as follows:—The space *a'* about the periphery of the lower muller is filled with quicksilver, and the pan nearly filled with pulp, of the proper consistency to flow easily; the shaft C is now made to revolve at a proper speed, from sixty to eighty revolutions per minute, by which the upper muller is rotated. The pulp between the mullers, by means of the centrifugal force developed, is made to pass out through the radial channels between the dies, as well as between the grinding surfaces of the upper and lower mullers; also into and over the quicksilver, thereby causing *amalgamation*.

116.



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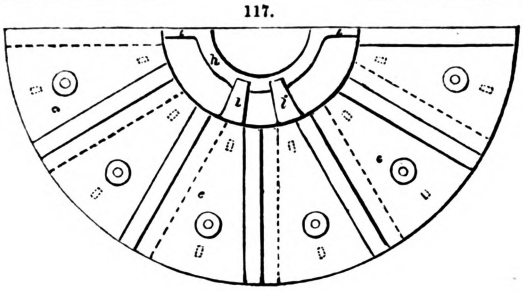

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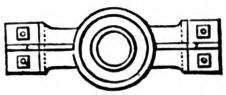

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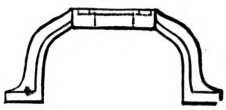


120.

The outward motion of the pulp has the effect of keeping the quicksilver entirely away from the grinding surface, thereby obviating what has often proved a very serious difficulty, the grinding of the mercury.

The rotation of the upper muller causes the pulp in the pan to revolve with it. This current is met by the cuneiform projections and curved plates, and thereby turned towards the central opening in the upper muller. The radial slots between the shoes, running from the central opening to the outward one, allow currents of considerable size to pass with great velocity; and the pump filling these slots, being continually thrown outwardly, tends to produce a vacuum. By this the pulp in the body of the pan is set in motion, causing a rapid and abundant flow downwards at the centre, and upwards along the inner surface of the pan. The pulp is thus made to circulate, until complete pulverization of the quartz and amalgamation of the metals have taken place.

*Reference.*—A, pan or tub; B, cover; C, vertical shaft; D, central tube; E, exterior tubes; F, boss of driving-wheel; G, hub of outer tube; H, sliding bearing; J, hand-wheels; O, adjustable box; V, flange of outer tube; *a*, lower muller; *a'*, space for mercury; *b*, upper muller; *c*, shoes of muller; *d*, hole in centre of lower muller; *e*, bolts securing lower muller; *f*, bolts securing shoe to upper muller; *h*, ring on upper muller; *i*, curved arms of muller; *k*, sliding key; *j*, lugs to keep shoes in place; *l*, set-screws; *m*, Babbit's metal bearing; *q*, rings supporting curved plates; *r*, curved plates; *s*, flanges of curved plates; *t*, brackets supporting plates; *w*, fulcrum of lever; *x*, hand-wheel for lifting muller.

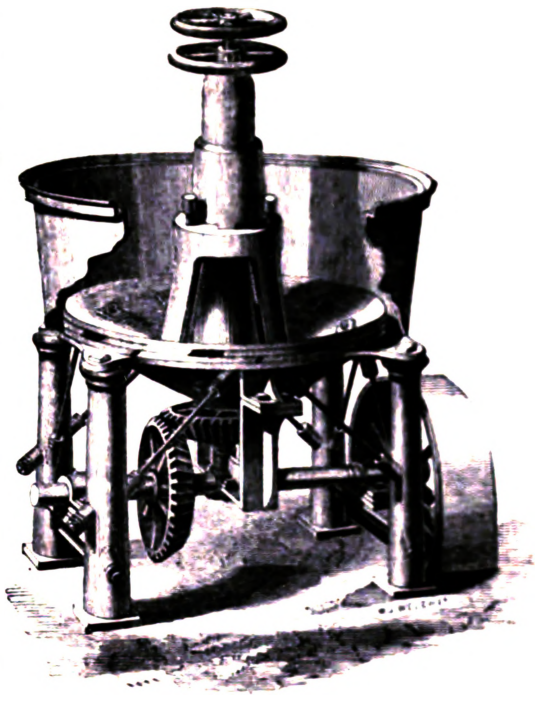
AMALGAMATION PAN. Fr., *Cuvette à amalgamer;* Ger., *Amalgamamir-pfanne;* Ital., *Bacino per amalgamare;* Span., *Máquina para amalgamar.*

This pan, shown in Fig. 121, differs from ordinary pans which are employed for the same purpose, especially in the shape of the bottom. The bottom of this pan is inclined towards the centre, and is shaped like the inverted frustum of a cone, to which the shoes are bolted, and the corresponding dies are fastened to the bottom of this frustum. When the pulp is thrown in and the *Mullers* set in motion, that portion of the pulp which finds its way between the grinding surfaces is thrown towards the circumference, from whence it again descends to the centre by gravitation, and passes between the mullers. A constant circulation is thus established without the aid of the curves or wings employed in the Wheeler Pan, which have sometimes been found an impediment in starting the machine after the sand had become packed from stopping. The charge for this pan is about 1400 lbs., and the time required for working it is from two to four hours. The time varies in accordance with the fineness, state of division, and other characteristics of the pulp. When the ore has been sufficiently reduced and amalgamated, the pulp is, after dilution, discharged into the *separator*, and the amalgamating pan immediately recharged without stopping the machine. After the pulp has been run off into the separator, it is further thinned down with water to such a consistency as will allow the mercury and amalgam to settle, whilst it still retains sufficient plasticity to hold the coarser particles of ore in suspension in water. If the compound be in a proper state of dilution, the mercury and amalgam will gradually precipitate, and at the same time no perceptible difference will be felt in the consistency of the pulp situated near the bottom

and that at the top of the vessel. When, however, too large a portion of water has been added, the coarser particles will be felt to distinctly separate from the slime, and to strike against the hand when placed near the bottom of the separator. This pan usually makes between fifty and sixty revolutions a minute.

The Hepburn and Peterson Pan is much employed in the reduction establishments of the Pacific Coast, and, in addition to being an excellent amalgamator, it is also a good grinder; but it has the disadvantage of requiring the expenditure of from four to five horse-power for efficient working. The charge of the Wheeler Pan is not only less than that of the Hepburn and Peterson Pan, but the grinding power of the Wheeler Pan is also less considerable. See SILVER.

121.



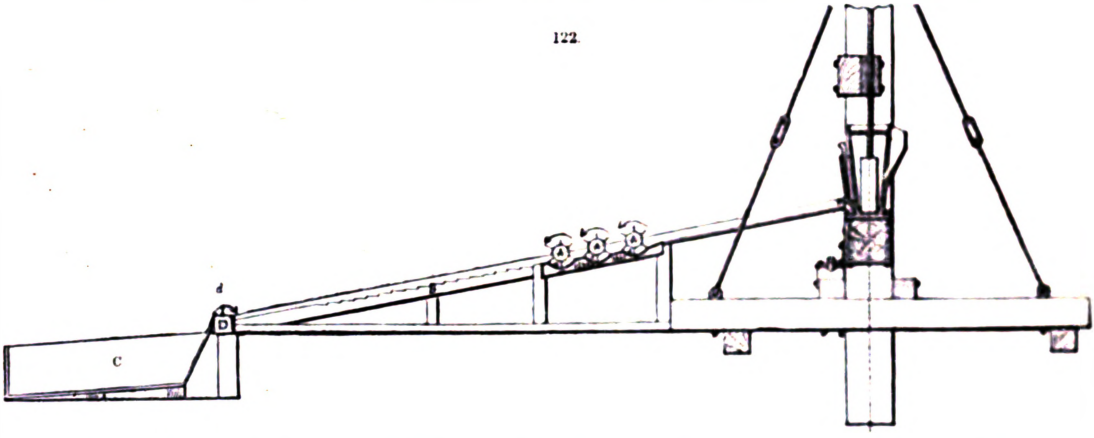
AMALGAMATING-PAN. FR., *Machine à amalgamer*; GER., *Amalgamir-pfanne*; ITAL., *Apparecchio per amalgamare*; SPAN., *Máquina para amalgamar*.

AMALGAMATOR, *Attwood's*. In gold mining.

Attwood's amalgamator is shown in Figs. 122, 123, 124, 125: it is designed to save the gold as it issues from the stamping mill. Fig. 122 is a sectional elevation; Fig. 123, plan; Fig. 124, lower end of tyers; and Fig. 125, end of steam-chest.

In this arrangement Attwood does not make use of blankets, but the ground ore, issuing from the battery-screens, flows directly on to the amalgamator, where it is gently stirred by the action of the cylinders A, turning in the direction indicated by the arrows, and then passes on to a riffle-board B, covered by amalgamated copper-plates, where a great portion of the amalgam, escaping from the cast-iron mercury boxes *a*, will

122.



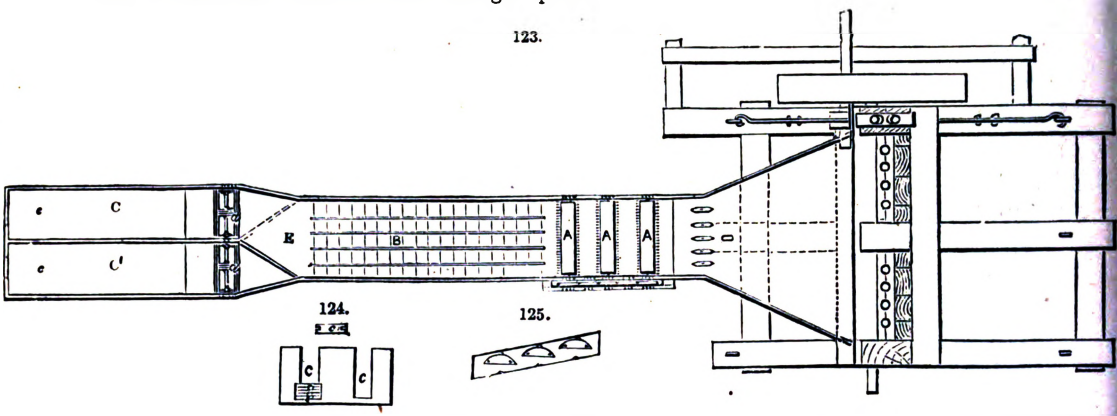

be collected. In order that the mercury in the boxes under the rollers may not become too cold, and its affinity for gold be thus rendered sluggish, they are cast with a double bottom, through which a current of steam can be made to pass, and which is easily regulated by an ordinary tap.

From the riffles B, the ground material passes into the tye C, of which the bottom is inclined at a considerable angle, and which is provided at the lower end with a slot *c*, for regulating the depth of water within it. This is done by means of the stops *c'*. In order to catch any globules of soft amalgam or mercury, which may become detached from the surface of the amalgamated plates, a small cistern D, running the whole width of the riffle-board, is provided; in this is an agitator *d*, turning in the direction indicated by the arrow, and which constantly keeps the box, to the depth of its arms, free from accumulations, so as to form a depression in which the mercury and amalgam may become deposited.

To use this apparatus, one of the stops *c'* is placed in the slot *c*, and the mill started in the usual way; the sand which has passed through the amalgamator soon reaches the tye, and the heavier portions begin to accumulate behind the stop, whilst the lighter particles are carried off by

the current. The removal of the light sand is facilitated by gently sweeping the surface of the deposit upwards against the stream with a light broom, a boy being stationed there for that purpose; and when the pyrites which is deposited accumulates to the height of the top of the first stop, another is inserted, and the operation carried on continuously. When one of the tyes has been filled in this way, the tongue E is so turned as to direct the sand and water into the other, which is thus filled whilst the first is being emptied.

123.




124.




125.



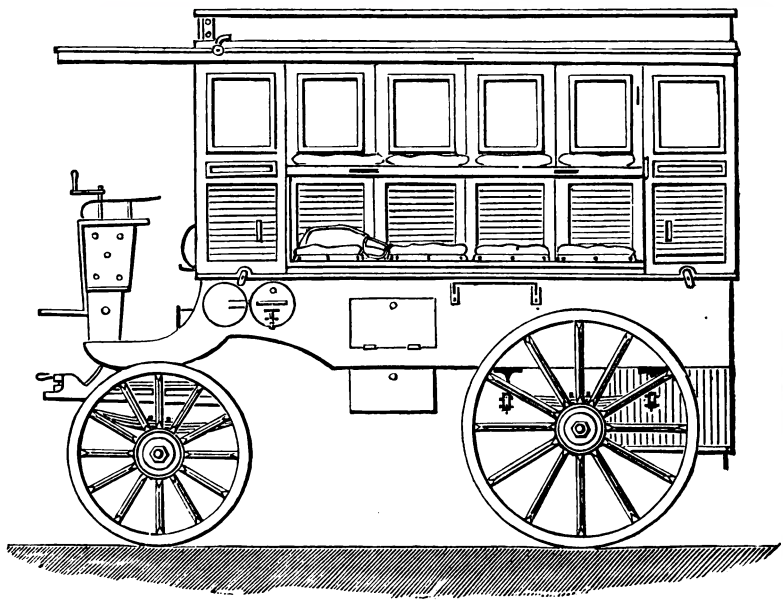
It is evident that by this means the pyrites will be collected in the tyes in a very concentrated form, and that the amount of labour required is but small; we have, however, never seen this apparatus in operation, and are without any precise data showing its efficiency, as compared with the blankets and riffles now in general use.

*Reference.*—A, agitating rollers with iron blades; *a*, mercury troughs; B, copper riffles; C C', tyes; *c c*, apertures at bottom of tyes; *c' c'*, stops for bottom of tyes; D, trough for collecting mercury and amalgam; *d*, agitator in trough; E, tongue for directing course of tailings into tyes C and C'.

AMBULANCE. Fr., *Ambulance;* Ger., *Feldhospital;* Ital., *Ambulanza, Ospitale ambulante;* Span., *Ambulancia militar.*

A variety of contrivances have been invented for the conveyance of soldiers wounded in battle; the main object of these contrivances, termed ambulances, is to remove the men with the least possible suffering, and to place them, consequently, in an easy position, consistent with the limited space allotted for this purpose, or until they can be removed to an infirmary or military hospital. Fig. 126 represents a carriage designed to carry five wounded men; such carriages are employed

126.

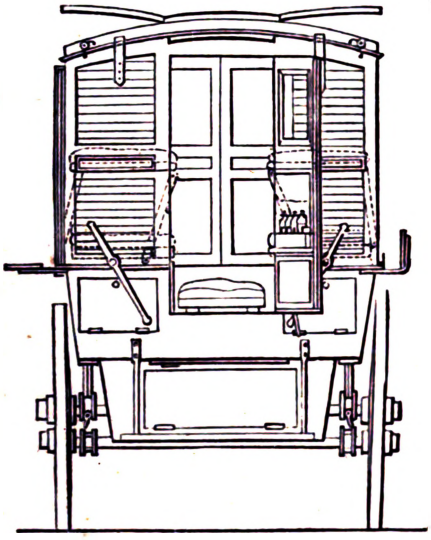


in the Italian army, and constructed according to directions given by Dr. Bertani. The inside of the body of the carriage, Fig. 126, contains five beds, namely, two on the side-seats, which are placed lengthwise in the body of the carriage, and two above these supported by beams which are fixed to iron pillars or supports; the fifth bed is placed at the bottom of the body of the carriage between the seats. The carriage is made to open sideways, so as to give facility to place the wounded men on the beds, which rest on flat steel springs that act with ease, in consequence of

their nicely adjusted power of elasticity. Tanks, made of zinc, are placed under the supports of the beds; these tanks are fitted with suitable gutta-percha tubing, which carries off the fluids that escape, to funnels which communicate with openings under the carriage where the fluids are discharged. The upper beds, by means of a suitable mechanical contrivance can be lowered so as to obviate any difficulty that might arise in placing the men upon them with ease and rapidity; the beds, with the wounded men, are replaced by the same mechanical contrivance. The frame-work of the vehicle shown in Fig. 126 is solidly and well built; the body is supported upon six springs of the best make; ventilation is amply provided; and great care has been taken to exclude strong light, which might interfere with the comfort of the temporary occupants.

Fig. 127 is an end view of the carriage shown in Fig. 126; the door at the back is shown in Fig. 127; it is strongly made, and on its inside there are pockets which hold bottles of medicine and other necessaries. The driver's seat is constructed to carry three persons—two and the driver. This convey-

127.



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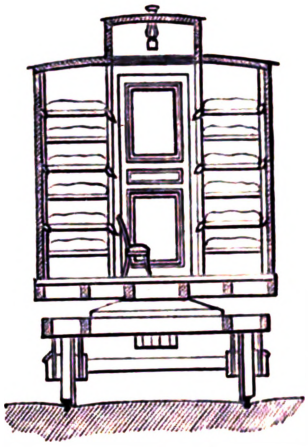

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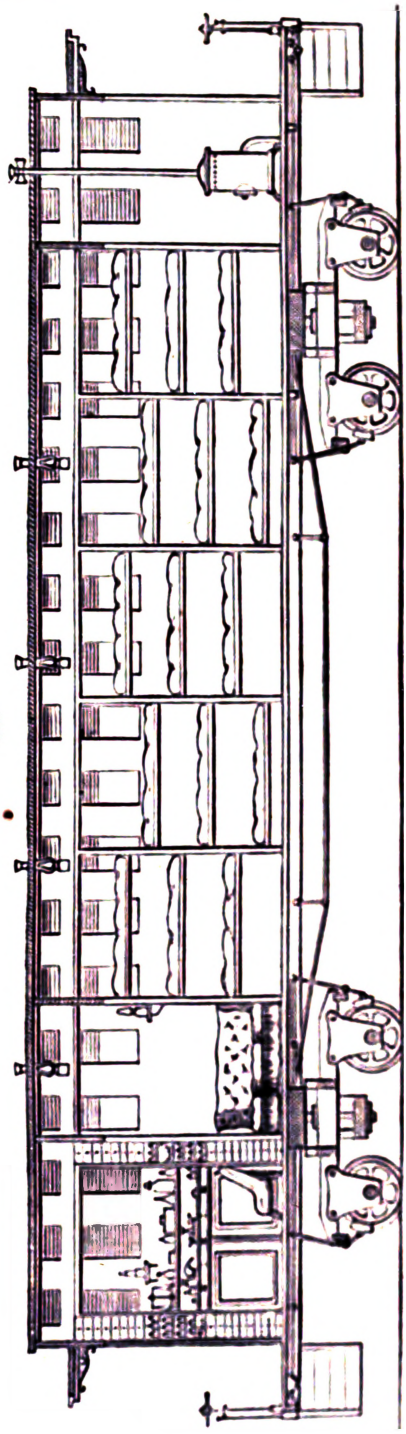


ance, shown in Figs. 126, 127, is light, and may be easily drawn over bad roads or through fields by two horses.

Fig. 128 represents an American hospital railway-waggon, fitted up for thirty men. This

waggon or carriage is about sixty-five feet long; it is divided into two parts, one of which contains a chemist's shop and a surgery, together with a small compartment for attendants. At the opposite end there is a small compartment for the guard and breaksman. The beds are supported by strong straps of vulcanized india-rubber. This ambulance, Fig. 128, is properly lighted and ventilated, and, when necessary, it can be heated by a stove. Fig. 129 is an end view of the carriage shown in Fig. 128. Strong breaks, similar to those used on ordinary American railway-carriages, are applied to the wheels of this ambulance both fore and aft.

AMMUNITION. Fr., *Munition de guerre;* Ger., *Krieys-ammunition;* Ital., *Munizione;* Span., *Municiones de guerra.*

See Ordnance. Small-arms.

ANCHOR. Fr., *Ancre;* Ger., *Anker;* Ital., *Ancora;* Span., *Ancla.*

An anchor is an instrument employed for obtaining a temporary hold of the ground, either under water or on land, but principally in the former position. By its use a strain may be resisted, as in the case of the ship at single anchor, or moored; or a fixed point may be obtained on which to exert power, as in the case of a vessel aground, the anchors of which, being laid out at a distance, enable her to be *hove off* by power exerted on board.

The shapes of anchors are various, to fulfil special objects. The weights range from the 112-cwt. anchors of the 'Great Eastern,' down to those of the smallest yacht; but the proportion to tonnage now employed in the Royal Navy is given in the following Table:—

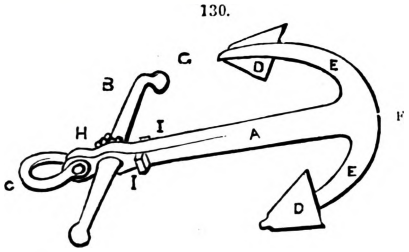
| Anchors. | Line of Battle Ships. | | | | Frigates. | | | | Corvettes. | | | | | | Despatch Vessels. | | | Gun-Boats. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Above 3500 Tons. | Above 2700, under 3500 Tons. | Above 2000, under 2700 Tons. | Under 2000 Tons. | Above 3500 Tons. | Above 2700, under 3500 Tons. | Above 2000, under 2700 Tons. | Under 2000 Tons. | Above 1600 Tons. | Above 1100, under 1600 Tons. | Above 960, under 1100 Tons. | Above 700, under 960 Tons. | Above 500, under 700 Tons. | Under 500 Tons. | Above 800 Tons. | Above 600, under 800 Tons. | Under 600 Tons. | Above 250 Tons. | Under 250 Tons. |
| | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. | Cwts. |
| Bower .. | 100 | 95 | 90 | 75 | 85 | 75 | 70 | 60 | 50 | 45 | 40 | 30 | 25 | 20 | 25 | 20 | 14 | 9 | 7 |
| Stream .. | 30 | 25 | 25 | 20 | 25 | 20 | 20 | 18 | 14 | 12 | 10 | 9 | 7 | 6 | 7 | 6 | 6 | 5 | 3 |
| Kedge .. | 9 | 8 | 7 | 5 | 7 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | .. | .. | .. | .. | .. |

The average appears to be about $\frac{1}{850}$th part of the tonnage for bower anchors of the larger classes; one-third of this for the stream, and $\frac{1}{11}$th for the kedge.

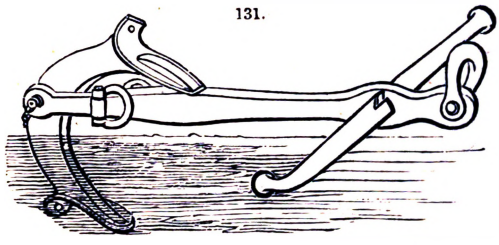
Among solid anchors the best form is that of the British Admiralty, shown in Fig. 130; it consists of a *shank* A, with two hooked arms E, E, termed *flukes*, and a *stock* B; the shank A has a ring or *shackle* C, at the end. That end of the shank which is next the stock is called the small round; the point F, where the arms and shank unite, is termed the *crown;* and the rounded angle at its junction with the arms, the *throat*. The arms, for about half their length, are made either round or polygonal; the remaining half consists of three parts, namely, the blade, the palm, and the bill. The blade or wrist is the continuation of the arm towards the palm or fluke D, which is a broad, flat, triangular plate of iron fixed on the inside of the blade. The *bill* or *pea* G, is the extremity of the arm. I, I, are projections intended to enable a wooden stock to be applied in case of necessity. The *forelock* and its chain are shown at H, Fig 130.

Among hinged anchors the best forms are those of the Porter or Trotman, shown in Fig. 131, and the Martin, Fig. 132, which has the peculiarity of holding with both flukes.

130.




131.



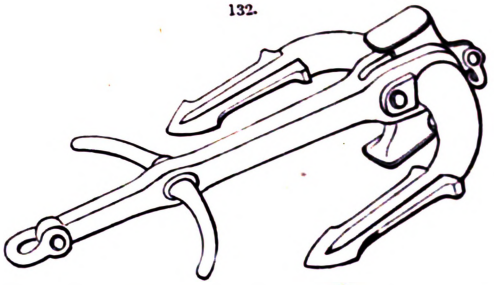
The chief requisites of a good anchor are solidity, holding-power, and non-liability to "fouling." Also the anchor must be easy to "cat" and "fish," and certain to "bite" when a strain is applied.

And here a comparison may be useful between the old form of anchor, as the Admiralty (*vide sup.*) and hinged anchors. While one fluke of the old form must always be standing up out of the ground ready to go through the bottom of an iron ship, or to inflict serious damage on a wooden one, and is always likely to catch the "bight" of the chain cable as it is dragged round when a gale arises and the ship swings to her anchor, and thus cause a foul anchor,—the hinged anchor has no such inconvenience, and in the case of Martin's has a far better hold of the ground. Against this, in the Admiralty anchor are to be put the solid advantages of superior strength and simplicity.

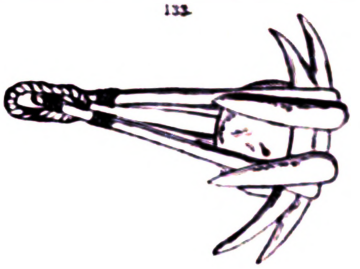
A rude but efficient form of four-fluked anchor is made of wood and stone, Fig. 133, and is still in use in eastern countries. The anchor of most civilized nations is made of wrought iron, but for this, as in chain cables, steel might with advantage be substituted. Since the introduction

of chain cables, a great part of the weight formerly considered necessary may be dispensed with, if the tensile strength remains the same. This is on account of the fact that the weight of chain lying on the mud or ooze at the bottom contributes so much to hold the ship, that she rarely "looks

132.



133.

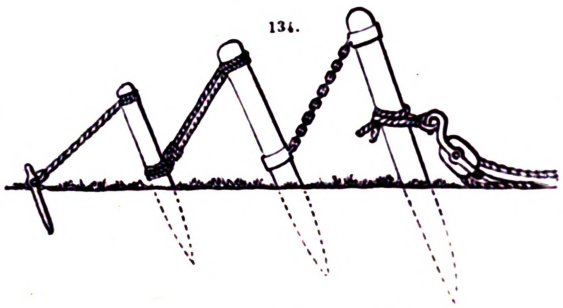


at her anchor" unless in a heavy gale. A useful form of land-anchor is that where, instead of an anchor of the ordinary type, posts of wood or bars of iron are made to do the same duty, Fig. 134.

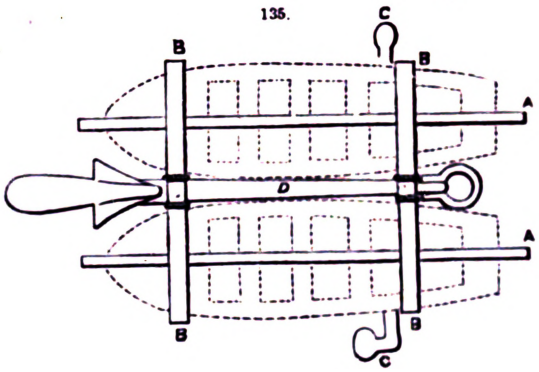
The laying out of large anchors in case of disaster at sea is best accomplished by the use of two boats of similar size, between which the anchor is slung, Fig. 135. A, A, are spars lashed fore and aft in the boats; B, B, are larger and shorter spars, which rest on A, A, and support the anchor hung below; C, C, stock of anchor; D, the anchor.

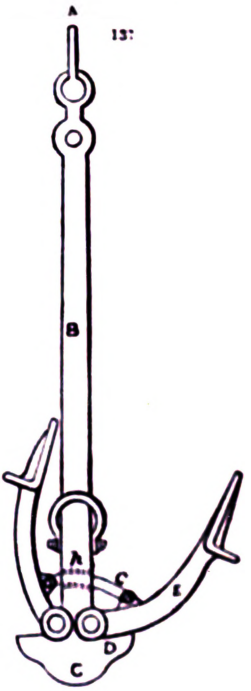
Every man-of-war has two "bower" anchors—the best and the small; a sheet anchor, same size as the best bower; a spare anchor, ditto; and a stream anchor; with two or more "kedge" anchors of smaller size. The two bower anchors, as their name implies, are always at the bows,—best bower starboard side, small bower port side, secured to the "cat-heads" and "fish-bollard;" sheet anchor starboard side, abaft fore-chains; spare ditto ditto port side; the others as most convenient, but all generally outside the ship's gunwale, where they may easily be got at in case of necessity. The mushroom anchor for moorings is shown in Fig. 136.

134.

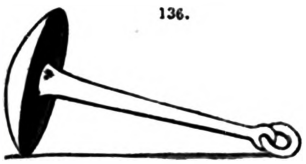


135.




136.



137.

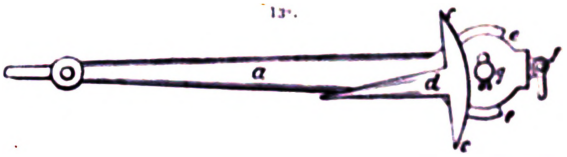


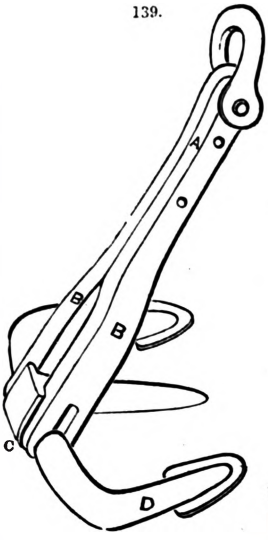

Fig 137 represents the anchor of E. R. C. Morgan; it consists in the arrangement of two flukes, E, hinged to the anchor-shank B, by separate bolts, D, independently of each other; the two flukes are connected by means of a segment G, passing through a slot A, in the shank B.

The anchor of E. Snell, Fig. 138, has four horns, c, c, fixed to the movable arms d, which take

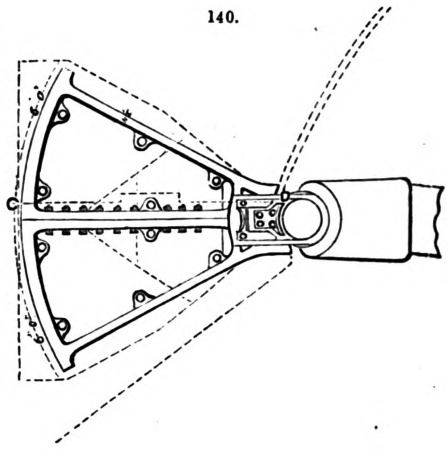
double grip when the anchor is moved by the cable along the holding-ground. A strong key-bolt *g*, acts as a hinge at the turning point; the range of the motion is limited by the *cams c, e*. A shackle *f*, is fixed at the crown. The horns *c, c*, cause the anchor to lie on the ground in the right position, and compel the palms to penetrate the ground and take hold at once. The use of a stock on the shank *a*, in this anchor is dispensed with. It has great holding power, lightness, facility of stowage, non-liability to foul, and facility of withdrawal from foul ground or obstructions.

The anchor of F. J. Latham is shown in Fig. 139. It consists of a shank A, with two flukes, D, pivoted to a stock B, which vibrate on either side of the latter to an extent determined by the contact of a crown-piece C, with the stock.

139.




140.



The anchor of the Victoria Docks, London, is a heavy iron casting, resembling a sextant in form, Fig. 140. The length of the curved part of the back is 12 feet, the arc being struck from the centre of the gate pivot with a radius C, D, of 11 feet. In consequence of its great size it was cast in two pieces, which were bolted together through the middle rib; it is held firmly in place by ten vertical bolts, 2 inches in diameter, taking hold of a mass of solid brickwork, 10 feet thick, by means of bed-plates nearly 70 feet in area. There are in addition two long raking bolts, passing through strong plates, bedded further back in the brickwork of the wall.

The anchor strap, which is of wrought iron, is 7 inches deep and 2 inches in thickness, increased to 5 inches in the middle of the length. The ring or upper axis of the gate which it surrounds is 18 inches in diameter. It is formed of a piece of forged iron firmly riveted to a wrought-iron plate ¾ of an inch thick, on the top of the gate, which is stiffened by additional gusset-pieces and angle-irons. The strap is adjusted by means of keys; and provision is made for examining them and the strap with facility.

### Anchors, Chain-cables, and Hawsers of Merchant-ships,

*According to Lloyd's Rules.*

| Ship's Tonnage. | Anchors. Number. Bower. | Stream. | Kedge | Weight. Bowers (excluding stock). | Bowers (Admrlty Test.) | Stream (including stock). | Kedge (including stock). | 2nd Kedge (including stock). | Stud-chain cables. Minimum Size. | Proved to Admiralty Test. | Length. | Hawsers and warps. Stream. Chain. | Rope. | Hawser. | Warp. | Length. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tons. | | | | Cwts. | Tons. | Cwts. | Cwts. | Cwts. | In. 16ths. | Tons. | Faths. | In. 16ths. | In. | In. | In. | Faths. |
| 50 | 2 | 1 | 1 | 2·25 | 4·7 | 1·00 | 0·50 | .. | 0 11 | 8·5 | 120 | 0 7 | 5 | 3 | .. | 90 |
| 75 | 2 | 1 | 1 | 2·75 | 5·2 | 1·50 | 0·75 | .. | 0 12 | 10·1 | 120 | 0 7 | 5 | 3 | .. | 90 |
| 100 | 2 | 1 | 1 | 4·00 | 6·4 | 1·75 | 1·00 | .. | 0 13 | 11·9 | 150 | 0 8 | 5·5 | 3 | .. | 90 |
| 125 | 2 | 1 | 1 | 5·25 | 7·6 | 2·00 | 1·00 | .. | 0 14 | 13·75 | 180 | 0 8 | 5·5 | 3·5 | .. | 90 |
| 150 | 2 | 1 | 1 | 6·00 | 8·2 | 2·50 | 1·25 | .. | 0 15 | 15·75 | 180 | 0 9 | 6 | 4 | .. | 90 |
| 175 | 2 | 1 | 1 | 7·25 | 9·5 | 2·75 | 1·25 | .. | 1 0 | 18·0 | 180 | 0 9 | 6 | 4 | .. | 90 |
| 200 | 3 | 1 | 1 | 8·25 | 10·4 | 3·00 | 1·50 | .. | 1 1 | 20·3 | 180 | 0 10 | 6·5 | 4 | .. | 90 |
| 250 | 3 | 1 | 2 | 10·00 | 12·0 | 4·75 | 2·25 | 1·00 | 1 2 | 22·75 | 210 | 0 10 | 7 | 5 | .. | 90 |
| 300 | 3 | 1 | 2 | 12·00 | 13·9 | 5·00 | 2·50 | 1·25 | 1 3 | 25·5 | 210 | 0 11 | 7·5 | 5·5 | .. | 90 |
| 350 | 3 | 1 | 2 | 13·50 | 15·2 | 6·00 | 3·00 | 1·50 | 1 4 | 28·1 | 240 | 0 11 | 7·5 | 5·5 | .. | 90 |
| 400 | 3 | 1 | 2 | 15·25 | 16·7 | 6·50 | 3·25 | 1·75 | 1 5 | 31·0 | 240 | 0 12 | 8 | 6 | .. | 90 |
| 450 | 3 | 1 | 2 | 16·75 | 18·0 | 7·00 | 3·50 | 1·75 | 1 6 | 34·0 | 270 | 0 12 | 8·5 | 6·5 | .. | 90 |
| 500 | 3 | 1 | 2 | 18·00 | 19·0 | 8·00 | 4·00 | 2·00 | 1 7 | 37·2 | 270 | 0 13 | 9 | 7 | .. | 90 |
| 600 | 3 | 1 | 2 | 21·00 | 21·6 | 9·00 | 4·50 | 2·25 | 1 8 | 40·5 | 270 | 0 13 | 9·5 | 7 | 4 | 90 |
| 700 | 3 | 1 | 2 | 23·50 | 23·5 | 10·00 | 5·00 | 2·50 | 1 9 | 44·0 | 300 | 0 14 | 10 | 8 | 5 | 90 |
| 800 | 3 | 1 | 2 | 25·50 | 25·2 | 10·50 | 5·25 | 2·75 | 1 10 | 47·5 | 300 | 0 14 | 10 | 8 | 5 | 90 |
| 900 | 3 | 1 | 2 | 27·75 | 26·9 | 11·00 | 5·50 | 2·75 | 1 11 | 51·2 | 300 | 0 15 | 10 | 9 | 5·5 | 90 |
| 1000 | 3 | 1 | 2 | 30·00 | 28·6 | 12·00 | 6·00 | 3·00 | 1 12 | 55·1 | 300 | 0 15 | 10 | 9 | 5·5 | 90 |
| 1200 | 3 | 1 | 2 | 32·00 | 30·1 | 13·00 | 6·50 | 3·25 | 1 13 | 59·1 | 300 | 1 0 | 10 | 9·5 | 6 | 90 |
| 1400 | 3 | 1 | 2 | 34·00 | 31·6 | 13·50 | 6·75 | 3·25 | 1 14 | 63·25 | 300 | 1 0 | 10 | 10 | 6 | 90 |
| 1600 | 3 | 1 | 2 | 36·50 | 33·4 | 14·00 | 7·00 | 3·50 | 1 15 | 67·5 | 300 | 1 1 | 11 | 10·5 | 6·5 | 90 |
| 1800 | 3 | 1 | 2 | 38·00 | 34·5 | 14·50 | 7·25 | 3·50 | 2 0 | 72·0 | 300 | 1 1 | 11 | 11 | 7 | 90 |
| 2000 | 4 | 1 | 2 | 40·00 | 35·7 | 15·00 | 7·50 | 3·75 | 2 1 | 76·5 | 300 | 1 2 | 11 | 11 | 7 | 90 |
| 2500 | 4 | 1 | 2 | 42·00 | 37·1 | 17·00 | 8·50 | 4·25 | 2 2 | 81·3 | 330 | 1 2 | 12 | 12 | 8 | 90 |
| 3000 | 4 | 1 | 2 | 45·00 | 39·2 | 19·00 | 9·50 | 4·75 | 2 4 | 91·1 | 360 | 1 3 | 12 | 12 | 8 | 90 |

Two of the bower anchors must not be less than the weight set forth above, but in the third a reduction of 15 per cent. is allowed. All anchor-stocks must be of acknowledged and approved description.

Unstudded close-link chains of 1 inch in diameter and under, are admitted as cables, if proved to two-thirds the test required for stud-chains. But in all such cases a short length, not less than 12 links, must be tested up to the full strain for stud-link chains.

In cases where parties are desirous of using or supplying chains of smaller size than is set forth above, a reduction is allowed not exceeding $\frac{1}{16}$th of an inch in chains of 1 inch to 1¼ inch diameter, and $\frac{1}{8}$th of an inch in chains above 1¼ inch diameter, provided they be subjected to the Admiralty strain for the size for which they are to be substituted; and further, that a few links, not less than twelve, to be selected by the tester, shall be proved to the breaking strain, and show a margin of at least 10 per cent. beyond the Admiralty proof for a chain of the full size required by the Table.

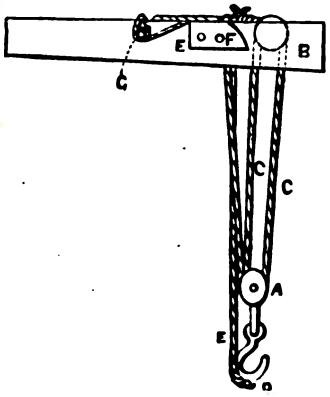
For steamers the anchors and cables will not be required to exceed, in weight and length, those of a sailing vessel of two-thirds their total tonnage.

ANCHOR-TRIPPER, or ANCHOR-STOPPER. FR., *Arrangement mécanique pour vitement détacher l'ancre et le faire tomber dans l'eau*; GER., *Eine Vorrichtung zum schnellen Werfen der Anker*; ITAL., *Apparecchio per gettar l'ancora*; SPAN., *Aparejo para soltar el ancla.*

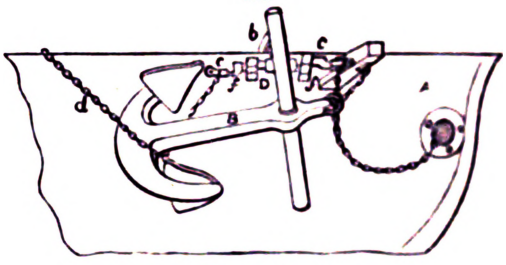
An anchor-tripper is a device for the purpose of relieving or forcing the anchor from the davit or cat-head. In the anchor-tripper of W. Stacy, Fig. 141, the tripping line E, turns the hook D, which holds the ring, thus permitting the ring to slide off its suspending hooks. A is a block; B, the davit or cat-head; and C a rope passing through the block and over the davit; F is a guide-block over which the rope passes, and G is a belaying-pin. Fig. 142 illustrates the manner in which the anchor-tripper of B. H. Heitmann is applied: A is a hawse-pipe, and B the anchor. To throw the anchor off from the rail with this tripper, it is only necessary to raise a lever *h*, which rests upon the rail; when this lever is raised, both the shank-painter and the ring-stopper are instantly discharged by the motion given to the rotating bar or keeper D, with its troughs *f*, *f*, chain *d*, and latches *c*, *c*.

The anchor-tripper of G. Gibson is shown in Fig 143. This invention consists in so forming or arranging upon the upper edge and inner side of the bulwarks of a vessel, and at or near the bow, a

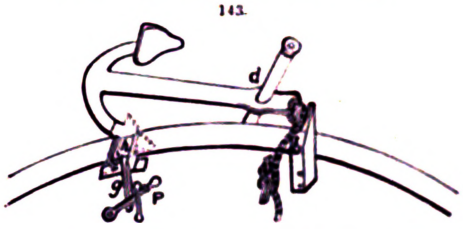
141.




142.




143.




resting surface or support *g*, *h*, for the fluke of the anchor, that when desired, by simply releasing or unfastening the said support by means of the detaining lever P', the anchor *d*, will readily fall and drop by its own weight.

*Works and Reports on Anchors*:—'Anchor-making' in Steel's 'Rigging and Seamanship,' 4to, 1793. Pering (R.), 'Treatise on the Anchor, with some Observations on Chain-cables,' royal 8vo, 1819. Rodger (Lieut. W.), 'Improvements in Anchors,' 8vo, 1830. Jamieson (A.), 'On the Mechanical Properties of Porter's Patent Anchor,' 8vo, 1843. Cotsell (G.), 'Treatise on Ships' Anchors,' 12mo, 1856. 'Parliamentary Reports on Anchors,' 1860, 1864. 'Rapports de la Commission du Ministère de la Marine sur l'Exposition de 1867,' Paris, 2 vols., 1868.

ANEMOMETERS EMPLOYED IN MINING OPERATIONS.

ANEMOMETER. FR., *Anémomètre*; GER., *Windmesser*; ITAL., *Anemometro*; SPAN., *Anemometro.*

The anemometers of which we treat are instruments designed to measure the force and velocity of currents of air in mines through chimney-shafts and in other places. Meteorologists employ machines, termed anemometers, which they employ to measure the force and velocity of the wind; of these machines we take no particular notice here.

*Means employed to Measure the Velocity of Air.*—The difficulty of measuring the velocity of the air with precision has been, and still is, the chief obstacle against the attainment of conclusive experiments which shall indicate the laws of the effort exerted.

The most general mode adopted by experimenters consists in throwing to the wind light bodies, such as feathers, thistledown, the smoke of powders, or the essence of turpentine, and in observing the distances described, with the corresponding times, in the movement of translation. But this simple method affords but little precision, on account of the small distances in which they can be observed; of which we shall speak presently.

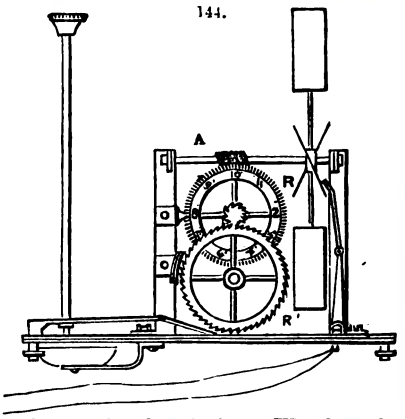
Anemometers, composed of a small light fan-wheel, whose motion is transmitted to a counter which registers the number of turns, are most certain, and convenient for use, though they must previously be tested, or the relation existing between the velocity of the wind and the number of turns of the wings must be accurately determined; this determination presents great difficulties.

Most generally, we accomplish this test by placing the instrument upon the horizontal arm of a species of horse-gin (Fig. 153) with a vertical axis, which is made to turn as uniformly as possible. We then observe simultaneously the number of turns of the wings and the velocity of translation of the instrument, and then suppose that the effect produced by this movement of the apparatus in the air the same as that which would be due to the action of the wind, impressed with the velocity of transport of the anemometer, upon the wings of the instrument at rest.

In examining the different systems of measuring the velocity of air in mines, we shall describe the construction and practical application of the anemometers now generally employed: the first we shall describe is a very light anemometer which M. Combes, Inspector-General of Mines, constructed to measure the small velocities of air, principally in the ventilation of mining works.

*Anemometer of M. Combes.*—This instrument is similar to Woltiman's mill for gauging streams of a considerable section. It is composed of a very delicate axle A (turning in agate caps), upon which are mounted four plane wings, equally inclined as to a plane perpendicular to the axis. In the middle of the axle (Fig. 144) is cut an endless screw, which drives a small wheel, R, with a hundred teeth, so that the latter advances one tooth for each revolution of the axle bearing the wings. The axle of the first wheel carries a small cam, which acts upon the teeth of a second wheel, R'. The last is held fast by a claw or very flexible steel spring, which is attached to the horizontal plate upon which the instrument is mounted. At each revolution of the first wheel with a hundred teeth, driven by the endless screw, the cam starts one tooth of the second wheel with fifty teeth. The two wheels are marked at intervals of ten teeth; the first from one up to ten, the second from one to five. The index-pointers, fixed upon light uprights, which bear the axle of the wings, serve to mark the number of teeth which each wheel has advanced, and thus to indicate the number of revolutions of the axle of the wings. By means of a detent and two cords, which move it, we may, at a distance, arrest the rotation of the wings, or allow them to turn, under the impulse of the current of air which strikes them.

144.




The manner of using this instrument is easily understood after this description. We place the limbs at zero, and the instrument in the axis of the air tubes, keeping the limbs immovable by means of a catch, which is loosened at the moment of commencing the observation, and made fast at the end of the same.

It is well to prolong the observation as long a time as possible, and for two or three minutes at least, if it can be done. The division of the limbs does not admit of counting over 5000 turns, which, for a velocity of air 9·84 feet per second, would only correspond with a duration of about 2·8 minutes.

The test or error of these instruments may differ very much from each other, though their dimensions may seem identical in all points. It should then be made for each one in particular, and repeated, as far as possible, whenever we wish to use it after an interruption.

Thus the anemometer, whose trial was reported by M. Combes, gave

$$v = 0{\cdot}8458 \text{ foot} + 0{\cdot}3005\, n,$$

$v$ being the velocity of the air in feet per second,
and $n$ the number of turns of the wings in 1″.

Another anemometer of the same model gave the relation

$$v = 0{\cdot}4921 \text{ foot} + 0{\cdot}3821\, n.$$

*Remarks upon the Use of the Instrument.*—This little instrument is handy for the measurement of small velocities, since we see that it can appreciate those from 0·492 to 0·82 foot per second. In this case it works long enough to give sufficiently exact indications in practice, still with this condition, that the current shall be continuous and tolerably regular, such as is the case with mines whose ventilation is produced by permanent causes, slightly varying from one instant to another.

*The Resistance of the Air.*—The phenomena produced by bodies moving in air are similar to those presented by liquids, and the resistance which it opposes to the motion of these bodies is of the same kind. Still, it is proper to distinguish between what occurs in uniform motion, and that which takes place in variable motion.

In the first case, the velocity remaining the same, the fluid molecules, successively driven aside by the body, experience the same displacements, receive the same velocities, and in different instants of its motion the body meets the same resistance. But in variable motion, accelerated, for example, the fluid molecules receive greater and greater degrees of velocity; and as they belong to an elastic fluid, the fluid prow formed in front of the body acquires a density and mass continually increasing, whence it follows that the mass displaced increases in the same time as the velocity

imparted to it. We conceive then, *a priori*, that the greater the acceleration of motion $\frac{v}{t}$, so will be the resistance; and so we may foresee that, in accelerated motion, the expression of the resistance of the air must comprise, besides other terms, one peculiarly due to the acceleration of motion itself. It was reserved, however, for the experiments of Morin at Metz for the first proving of this matter, to which we shall allude presently.

*Results of Experiments.*—The celebrated Borda made, in 1763, experiments upon the laws of the resistance of air, by means of a kind of fan-wheel, with a vertical axle and horizontal arms, a little over 7·15 feet in length. He placed at the end of this arm the surfaces and different formed bodies on which he wished to operate, and he observed the uniform velocities of the fly-wheel under the action of different weights. He thought the influence of the friction of this apparatus might be overlooked, which has occasioned some uncertainty in his results; for it is difficult to admit that, in dealing with so small a resistance, the portion of the motive weight engaged in overcoming the friction should not be comparable to that surmounting the resistance of the air.

Borda placed in succession, at the ends of the arms of his apparatus, square surfaces of 9·56, 6·38, and 4·25 inches at the sides, and set them in motion with weights of 8·8, 4·4, 2·2, 1·1, and 0·5 lbs., and consequently with different velocities. From the dimensions and data relative to this apparatus, the author has calculated the resistances of the air corresponding with the different velocities, and the results expressed in *yards* are given in the following Table:—

RESULTS OF BORDA'S EXPERIMENTS UPON THE RESISTANCE OF AIR.

| Surface of 9·591 inches each side, or of ·07099 square yard. | | | Surface of 6·394 inches each side, or of ·03155 square yard. | | | Surface of 4·263 inches each side or of ·01402 square yard. | | |
|---|---|---|---|---|---|---|---|---|
| Resistance of Air. | Velocities. | Squares of Velocities. | Resistance of Air. | Velocities. | Squares of Velocities. | Resistance of Air. | Velocities. | Squares of Velocities. |
| lb. | yards. | | lb. | yards. | | lb. | yards. | |
| 0·16695 | 3·787 | 14·34 | 0·16713 | 5·938 | 35·26 | 0·1592 | 9·053 | 81·94 |
| 0·07895 | 2·690 | 7·237 | 0·08356 | 4·199 | 17·64 | 0·0796 | 6·397 | 40·93 |
| 0·04168 | 1·891 | 3·579 | 0·0416 | 2·978 | 8·86 | 0·0399 | 4·505 | 20·30 |
| 0·02084 | 1·334 | 1·780 | 0·02083 | 2·091 | 4·28 | 0·01986 | 3·84 | 10·14 |
| .. .. | .. | .. | 0·01036 | 1·382 | 1·91 | 0·00944 | 2·252 | 5·07 |

If we represent these results graphically, in taking the resistances for abscissæ, and the squares of velocities for ordinates, we find all the points relative to the same surface are situated in a straight line, thus indicating that the resistance increases as the square of the velocity. The small extent of surfaces used by Morin could not manifest with certainty the existence of a constant term in the expression of resistance.

Comparing these results with the formula $R = K_1 A V^2$ (expressed in yards and square yards), we have for $K_1$ the following values:—

Square of 9·585 in. or 0·26575 yd., side, $K_1 = 0·1618$.
Square of 6·390 in. or 0·17716 yd., side, $K_1 = 0·1472$.
Square of 4·263 in. or 0·1181 yd., side, $K_1 = 0·1382$.

The coefficient $K_1$ is for A in square yards, and V in yards.

It is to be observed that Borda having neglected the influence of friction, which increases with the resistance and the motive weights employed, the apparent diminution of the resistance for the smaller surfaces may be attributed to this cause.

*Experiments by M. Thibault upon Bodies in Motion in the Air.*—We are indebted to Thibault for numerous and very well executed experiments, published at Brest in 1832. He used for his experiments a fly-wheel with two wings, turning on a horizontal axle, and moved by a weight, which the resistance of the air itself soon rendered uniform. This very light wheel was composed of a steel axle 2·13 ft. in length by 0·016 ft. square, terminated by journals with a diameter of 0·0082 ft. The arms of the fly were each formed of an iron rod 8·97 ft. long by 0·045 ft. wide in the direction of movement near the axle, and 0·016 ft. near the ends, with a constant thickness of 0·019 ft. in a direction parallel to the axle. The side of the arm striking the air was beveled.

The wings were mounted upon the arms of the flyer, and at first directed in planes passing through the axis; then by means of suitable arrangements they were inclined, 1st, in turning them around the radius; 2nd, in turning them round parallel to the axis, so that their direction left the axis either in the front or in rear. The inclinations thus obtained were varied at intervals of five degrees, and were carefully measured. The motion of the fan-wheel was produced in all cases by the same motive weight of 8·82 lbs., and the duration of twenty turns made with uniform motion was observed.

Morin calculated the results of the experiments of M. Thibault, in applying the formula

$$R = K_1' A + K_1 A V^2,$$

which represents, as we shall see hereafter, all the results of the experiments made at Metz. In giving to the coefficient $K_1'$ relative to the constant resistance independent of the velocity, the value $K_1' = 0·08002$ (units of yards), derived from these experiments upon a fan-wheel, we are enabled to deduce the value of the coefficient $K_1$ dependent upon the velocity. The inclination of the surface of the wings towards the direction of the motion was also taken, by introducing in the second term of the formula, in place of the area A = 0·12323 square yard, its projection upon a plane perpendicular to the direction of the motion.

EXPERIMENTS OF M. THIBAULT UPON THE RESISTANCE OF AIR.

| Inclination of Surfaces. | Time of 20 revolutions of Wheel. | Velocity of centre of the Wings. | Total resistance of each Wing. | Part of the resistance independent of the Velocity. | Resistance proportional to the square of the Velocity. | Ratio of the resistance to the square of the Velocity. | Projection of surface upon plane perpendicular to Motion. | Resistance per square yard projected, and per yard of Velocity. |
|---|---|---|---|---|---|---|---|---|
| ° | seconds. | yards. | lb. | lb. | lb. | lb. | sq. yard. | lb. |
| 90 | 68·40 | 2·752 | 0·1660 | .. | 0·1563 | 0·02063 | 0·12323 | 0·16737 |
| 85 | 68·07 | 2·765 | 0·1658 | .. | 0·1561 | 0·02041 | 0·12278 | 0·16619 |
| 80 | 67·90 | 2·772 | 0·1658 | .. | 0·1561 | 0·02031 | 0·12139 | 0·16729 |
| 75 | 67·70 | 2·781 | 0·1658 | 0·0097 | 0·1561 | 0·02018 | 0·11904 | 0·16953 |
| 70 | 65·56 | 2·828 | 0·1655 | .. | 0·1558 | 0·01948 | 0·11581 | 0·1682 |
| 65 | 64·76 | 2·906 | 0·1655 | .. | 0·1558 | 0·01845 | 0·11169 | 0·1651 |
| 60 | 62·47 | 3·014 | 0·1651 | .. | 0·1554 | 0·01710 | 0·10673 | 0·1602 |
| 55 | 61·15 | 3·078 | 0·1648 | .. | 0·1551 | 0·01637 | 0·10095 | 0·1621 |
| 50 | 60·25 | 3·124 | 0·1648 | .. | 0·1551 | 0·01588 | 0·09440 | 0·1682 |
| 45 | 56·75 | 3·318 | 0·1642 | .. | 0·1545 | 0·01403 | 0·08714 | 0·1610 |
| 40 | 52·83 | 3·563 | 0·1635. | .. | 0·1538 | 0·01211 | 0·07921 | 0·1529 |
| 35 | 48·50 | 3·882 | 0·1622 | .. | 0·1525 | 0·01011 | 0·07084 | 0·1428 |
| 30 | 43·00 | 4·378 | 0·1602 | .. | 0·1505 | 0·00785 | 0·06161 | 0·1274 |
| 25 | 36·75 | 5·122 | 0·1569 | .. | 0·1472 | 0·00561 | 0·05208 | 0·1077 |
| 20 | 30·50 | 6·173 | 0·1549 | .. | 0·1452 | 0·00381 | 0·04214 | 0·0904 |
| 15 | 24·50 | 7·683 | 0·1411 | .. | 0·1314 | 0·00222 | 0·03189 | 0·0697 |
| 10 | 19· | 9·910 | 0·1220 | .. | 0·1123 | 0·00114 | 0·02137 | 0·0535 |

This Table contains the data of the experiments of M. Thibault, and the results of his calculations. The figures entered in the Table show that the resistance to the square yard of surface projected perpendicularly to the direction of the motion, and per yard of velocity, where the value of the coefficient $K_1$ of the formula, $R = K_1 A V^2$, does not decrease so long as the angle of inclination is not below from 50° to 60°.

*Remarks upon Wing-regulators and Windmills.*—It follows in the case of fan fly-wheels used as regulators of motion, where the wings are inclined and turn round the radius of the fly-wheel, that when the motive power is too feeble we do not have a diminution of resistance until the wings have passed the inclination of from 50° to 60°; and as these regulators should also serve to prevent the acceleration of motion when the motive power increases, and consequently then afford the greatest resistance, it would be well, in the normal state, to place them at an angle of about 35° with the plane perpendicular to the direction of the motion.

It seems that something analogous to this is produced in windmills, the sails of which are, by some special mechanism, made to incline when the wind has acquired too much intensity.

Experience shows, in fact, that this disposition, the aim of which is to check the velocity from being too greatly *accelerated* by the effect of squalls, does not fully attain its object, and that the mill, whose normal velocity is from five to six turns in one minute, by a good breeze from 16 to 19 feet of velocity per second, reaches that of from twenty-nine to thirty turns, and more, with greater winds.

*Experiments upon different formed Surfaces.*—M. Thibault has successively repeated the same experiments with concave cylindrical surfaces; he arrived at the same consequences, and has established the fact that, with an equal projection of surface, upon a plane perpendicular to the direction of the motion, the resistance increases gently with the curvature.

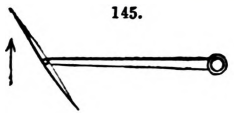
As for hollow surfaces, with double curvature, such as frame surfaces, the resistance increases with the curvature, and more rapidly than in the preceding case.

A comparison was made of the resistance offered by bent sails, with that experienced by plane sails with the same surface as that of the sails developed; the two surfaces of folded sails were each 0·1302 square yard, and the lower side was brought near the upper, as is usual with sails under the action of wind; and Thibault found that the resistance of the bent surface was the same as that of the plane surface, notwithstanding the diminution of the projection of the first surface upon the direction of the motion. A comparison is thus made between the increase of the resistance due to the curvature, and the diminution due to the narrowing of the projected surface.

This consequence is important, inasmuch as it facilitates the applications relative to the action of wind upon the sails of vessels.

*Influence of the Inclination of the Wings.*—It was found that when the vanes are inclined so that the axis of rotation is found in front of their plane, in regard to the direction of motion, Fig. 145, the resistance diminishes rapidly as the inclination increases, and that at the inclination of 55° it is not more than 0·5715 of the perpendicular resistance; while when the axis of rotation is found behind the plane of the wings, the resistance goes on increasing even up to the angle of 55°, Fig. 146, for which it is equal to 1·2293 times the perpendicular resistance.

145.



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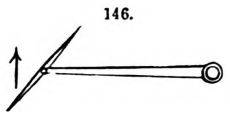

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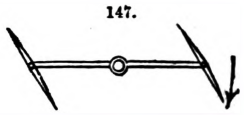


These results show that this mode of inclining the vanes of fly-regulators answers readily the proposed purpose, since in disposing them so that the vanes may be inclined at will in either direction, Fig. 147, the resistance experienced may be rendered greater or less, according to the necessities of the case.

The same experiments, repeated upon curved surfaces, with different degrees of inclination, have led to similar consequences, while indicating a still greater intensity of resistance than is experienced by plane surfaces. This explains the advantage which navigation derives from the movements of rotation impressed upon sails parallel to the axis of the masts.

*Influence of the Approximation of the Surfaces which are exposed to the Resistance of the Air.*—M. Thibault has also made some experiments to ascertain whether two equal surfaces (placed one behind the other, a very small distance apart) experience a less total resistance than when isolated. For this purpose he mounted upon his fly-wheel four wings, placed in pairs, the one behind the other, at a distance which he has not given, and he found for the case upon which he operated that the resistance of the posterior was not over $\frac{1}{4}$ of that of the anterior surface. This result, which can be applied to railroad trains, is important, and it was desirable that more complete experiments should be made upon this subject. See DYNAMOMETER, *Railway Car.*

*Influence of the Form of Surfaces.*—The same experimenter having placed at the extremities of his fly-wheel various surfaces of the same area, but of which two were square, two circular, and two in the form of a right-angled triangle, so that the centre of their figure was in all cases at the same distance from the axis, has observed that under the action of the same motive weight the fly-wheel took, in all cases, the same velocity, which shows that the resistance is independent of the form of the plane surfaces experimented upon.

*Resistance of Air to the Motion of Spherical Bodies.*—This particular case, which is of special interest in the study of the motion of projectiles in the air, has for a long time occupied the attention of philosophers and geometricians. Newton was the first to experiment upon this subject, in observing the fall of spherical bodies. Hutton and other observers have studied this resistance in the case of small velocities, by means of a rotating apparatus; and more lately the latter, in comparing the velocities of projectiles at different distances from the piece of ordnance, has extended his researches to great velocities.

Here, however, we limit ourselves to indicating the results more especially applicable to industrial questions.

From a summary of Newton's experiments upon the fall of glass globes in air, with velocities comprised between zero and 29·528 feet per second, at a mean temperature of 53·6°, and at a pressure of 2·46 feet, the value of the coefficient K, was about 0·0007137, so that the resistance experienced by spheres moved in the air, at velocities comprised within these limits, would be

$$R = 0{\cdot}0007137\ AV^2 = 0{\cdot}0007137\ \frac{D^2}{1{\cdot}273}\ V^2, \text{ for units of feet;}$$

$$\text{or } R = 0{\cdot}05781\ AV^2 = 0{\cdot}05781\ \frac{D^2}{1{\cdot}273}\ V^2, \text{ for units of yards;}$$

but in great velocities the coefficient of the resistance increases with the velocity; and after a discussion of Hutton's experiments, and those of the Commission at Metz, General Piobert has proposed, for a representation of the law of the *resistance of the air to the motion of projectiles*, the formula

$$R = 0{\cdot}03546\ AV^2\ (1 + {\cdot}002103\ V), \text{ units of yards,}$$
$$R = 0{\cdot}00043778\ AV^2\ (1 + 0{\cdot}0070102\ V), \text{ units of feet;}$$

which would indicate that, with these velocities, the expression of the resistance must contain a term proportional to the cube of the velocity, and that the constant term is without a sensible influence.

*Experiments at Metz upon Bodies moving in Air.*—Numerous experiments, with the joint labour of MM. Piobert, Didion, and Morin, were made at Metz in 1835 and 1837, which were more particularly made by M. Didion, in which they made use of chronometric apparatus to observe the law of the descent in air of different formed bodies, and of different dimensions. These experiments were made where the experimenters could avail themselves of a vertical fall of 46·916 feet.

The bodies employed were suspended upon a silk cord, wound round a pulley, which in its motion bore a style whose trace upon the plate of the chronometric apparatus, impressed with a known uniform motion, and observed at every experiment, furnished the law of motion of the descent of the body.

Special experiments were made to determine the passive resistances of the apparatus, to keep an account of them in the calculations.

Without going into a detailed discussion of the results, and the tests applied to them, we simply indicate the method adopted for the calculations.

MM. Morin, Piobert, and Didion, from their experiments upon the resistance of water, concluded that in the expression for the resistance of fluids there existed a constant term, and that of a term proportional to the square of the velocity. This conclusion was confirmed by the experiments which they made upon the resistance of air, obtained from uniform motion.

A first series of experiments, made upon a thin plate 1·267 sq. yd., gave for the expression of the resistance of the air,

$$R = 0{\cdot}0663 \text{ lb. } A + 0{\cdot}1372\ AV^2; \text{ in units of yards;}$$

but as the fall of 46·9 feet was not sufficient to give at the end of it a strictly uniform motion, and as we shall presently see that the resistance in variable motion must comprise a third term dependent upon the acceleration $\frac{v}{t}$ of motion, it follows that the term $0{\cdot}1372\ AV^2$, which comprises implicitly this third term, is a little too great, and should be diminished.

The existence of a constant term in the expression of the resistance was manifested in the experiments made upon a wheel with wings 1·09 yd. internal diameter, bearing square wings 0·2187 yd. by 0·2187 yd., twenty in number, presenting thus a total surface of 0·9568 sq. yd.

The results of these experiments were very exactly represented in the case or uniform motion by the formula

$$R = 0{\cdot}008892 \text{ lb. } A + 0{\cdot}001907\ AV^2 \cdot \text{ in units of feet,}$$

and

$$R = 0{\cdot}08002 \text{ lb. } A + 0{\cdot}1548\ AV^2; \text{ in units of yards,}$$

as may be seen in the following Table, in which the values found, at different uniform velocities, for the coefficient of the term proportional to the square of the velocity are very nearly constant.

EXPERIMENTS UPON THE RESISTANCE OF AIR TO THE MOTION OF A WHEEL WITH PLANE PLATES.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Uniform velocity of the centre of resistance of wings, in yards per second .. .. | yds. 2·89 | yds. 4·11 | yds. 5·17 | yds. 5·89 | yds. 6·69 | yds. 7·20 | yds 7·83 | yds. 8·28 |
| Resistance of wings reduced to the mean density of the air .. .. .. .. .. | lbs. 1·338 | lbs. 2·602 | lbs. 3·941 | lbs. 5·183 | lbs. 6·502 | lbs. 7·867 | lbs. 9·166 | lbs. 0·458 |
| Coefficient $K_1$ of the square of the velocity .. .. .. | ·15818 | ·15618 | ·15077 | ·15355 | ·14986 | ·15494 | 15494 | ·15818 |
| Mean $K_1$ .. .. .. .. .. .. .. .. .. = ·1548 | | | | | | | | |
| Velocity answering to the formula .. .. .. .. .. | yds. 2·918 | yds. 4·129 | yds. 5·108 | yds. 5·87 | yds. 6·58 | yds. 7·25 | yds. 7·83 | yds. 8·37 |

A review of the coefficient gives slight variations from those recorded by Morin, the mean of which would be $K_1 = 0{\cdot}1004$ instead of $0{\cdot}1002$.

This comparison of the results of experiments with those of the above formula show within what limits of exactness the latter represents the real effects.

*Method of Reckoning the Effects of Acceleration.*—It has been already shown that in elastic fluids the resistance must depend upon the acceleration of motion; and if these considerations are admitted, it follows that the resistance of the air in variable motion must be represented by a formula of the form of

$$R = K_1'A' + K_1 AV^2 + K_2 A \frac{v}{t}.$$

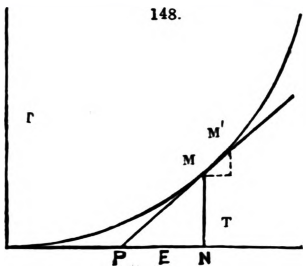
The experiments upon uniform motion having already furnished the approximate values of $K_1'$ and $K_1$, it remains to find that of $K_2$, or rather the term $K_2 A \frac{v}{t}$.

Without going into the details of the calculations, we limit ourselves to pointing out the method followed, since it shows a remarkable example of the advantages to be derived from a graphic representation of the law of motion.

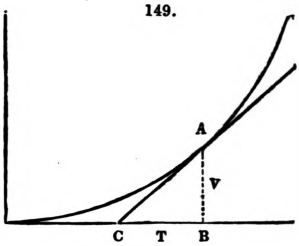
In the actual case, this law being represented by a continuous curve, whose abscissæ indicate the number of turns, or the spaces described, and whose ordinates express the times, it is clear that for one of these tangents, M P, for example, Fig. 148, the ratio of N P to M N, in the triangle M N P, will be the same as that of $e$ to $t$, representing by $e$ the infinitely small increase of the abscissa in passing from the point M to the infinitely near point M', and by $t$ the corresponding increase of time or of the ordinate: this ratio $\frac{e}{t}$ of the elementary path to the element of time in which it was described is precisely what is termed the velocity, which we express by the relation $V = \frac{e}{t}$; and we see that we may by means of the graphic trace of Fig. 148, form a table of the simultaneous values of the times and velocities, and so construct a new curve, whose abscissæ shall be the times T, and whose corresponding ordinates shall be the velocities V.

This new curve, Fig. 149, yields to analogous considerations; the tangents, at the different points, give us the ratio $\frac{AB}{BC}$, which is equal to the acceleration $\frac{v}{t}$, $v$ being the elementary increase of the ordinate or of the velocity V, and $t$ being always the elementary increase of the time.

148.




149.




Consequently, knowing at each instant the total resistance R, or the portion of the motive effort employed in overcoming the resistance of the air, as well as the coefficients $K_1'$ and $K_1$, we may calculate the term $K_2 A \frac{v}{t}$ and so deduce the value $K_2$.

This process may be abridged by operating upon that part of the curve relating to the end of the fall, since the variations of inclination of the tangents of the first curve are so small, that instead of tracing them, we may determine them by the value of the quotient $\frac{E-E'}{T-T'}$ of the difference of two consecutive spaces divided by that of the corresponding times.

This ingenious mode of discussion led M. Didion to assign to the coefficients of the formula, which represents the law of the resistance of air to the accelerated motion of descent of a plate 1·196 sq. yd. of surface, the following values:

$$R = 0{\cdot}06633\,\text{lb.} + 0{\cdot}1295\,V^2 + 0{\cdot}27652\,\frac{v}{t},$$

which is reduced in case of uniform motion to

$$R = 0{\cdot}06633\,\text{lb.} + 0{\cdot}1295\,V^2,$$

for one square yard of surface, V being in yards.

*Proof of the Exactness of this Formula.*—To show, *a posteriori*, that this formula, composed of three terms, represents the law of the resistance in accelerated motion more exactly than those which only contain a term proportional to the square of the velocity, or two terms, the one constant, and the other proportional to the square of the velocity, M. Didion has first sought for the values of the constant coefficients which it was proper to admit for each of these formulæ, so as to render them as exact as possible, and, after having found them, he calculated, by a very simple analytical method, the values of the times corresponding to the regularly increasing spaces described by the bodies, such as would be furnished by these formulæ, and he has compared them with the real times furnished by the curve of the law of motion. From the results of this comparison, which for one particular case are entered in the following Table, we see that the formula with three terms of resistance, represents, quite truly, the law of accelerated motion of the descent of a body in air, while the suppression of the term depending upon the acceleration $\frac{v}{t}$ does not admit of so exact a representation of this law, even in determining the coefficients so as to reproduce the calculated duration for one of the spaces, and that is also the case when we suppress the constant term.

The only results inserted in the Table are those of an experiment, during which the temperature was at 62°·24' (Fah.) and the barometric pressure at 2·465 feet of mercury.

COMPARISON OF TIMES AND VELOCITIES OF THE FALL OF A PLATE ONE MÈTRE SQUARE = 1·196 SQ. YD., OBSERVED AND CALCULATED.

| Spaces described. | Observed Durations. | Observed Velocities. | Durations calculated by the Formulæ (1) $R = 0{\cdot}66 + 0{\cdot}129\,V^2 + 0{\cdot}276\,\frac{v}{t}$ | (2) $R = 0{\cdot}066 + 0{\cdot}166\,V^2$ | (3) lb. $R = 0{\cdot}2076\,V^2$ | Velocities calculated by formula (1). |
|---|---|---|---|---|---|---|
| yds. | seconds. | yds. | seconds. | seconds. | seconds. | yds. |
| 0·0999 | 0·176 | .. | 0·178 | 0·160 | 0·160 | .. |
| 0·1993 | 0·254 | .. | 0·253 | 0·227 | 0·226 | .. |
| 0·2998 | 0·306 | .. | 0·310 | 0·278 | 0·277 | .. |
| 0·3994 | 0·359 | .. | 0·358 | 0·322 | 0·321 | .. |
| 0·4809 | 0·400 | .. | 0·400 | 0·360 | 0·358 | .. |
| 0·5997 | 0·428 | .. | 0·428 | 0·394 | 0·393 | .. |
| 0·6996 | 0·474 | .. | 0·473 | 0·419 | 0·417 | .. |
| 0·7996 | 0·508 | .. | 0·506 | 0·460 | 0 457 | .. |
| 0·8995 | 0·537 | .. | 0·536 | 0·488 | 0·487 | .. |
| 0·9995 | 0·566 | .. | 0·566 | 0·518 | 0 515 | .. |
| 1·2018 | 0·619 | .. | 0·622 | 0·570 | 0 567 | .. |
| 1·3998 | 0·679 | .. | 0·679 | 0·619 | 0 617 | .. |
| 1·5988 | 0·725 | .. | 0·723 | 0·665 | 0 663 | .. |
| 1·7990 | 0·771 | .. | 0·771 | 0·710 | 0 707 | .. |
| 1·9991 | 0·815 | .. | 0·820 | 0·748 | 0 746 | 3·46 |
| 2·9987 | 1·013 | .. | 1·013 | 0 947 | 0·943 | 5·46 |
| 3·9919 | 1·187 | 6·07 | 1·186 | 1·123 | 1·120 | 6·05 |
| 4·8098 | 1·346 | 6·50 | 1·346 | 1·289 | 1·287 | 6·49 |
| 5·9974 | 1·493 | 6·91 | 1·497 | 1·452 | 1·451 | 6·86 |
| 6·9970 | 1·636 | 7·25 | 1·639 | 1·607 | 1·606 | 7 14 |
| 7·9966 | 1·771 | 7·50 | 1·776 | 1·760 | 1·760 | 7·37 |
| 8·9962 | 1·910 | 7·60 | 1·912 | 1·912 | 1·912 | 7·56 |
| 9·8133 | 2·034 | 7·62 | 2·042 | 2·062 | 2·064 | 7·69 |

*Influence of the Extent of Surfaces.*—To establish this influence, M. Didion used a square plate, each side of which was 0·5468 yd., and so having an area of 0·299 sq. yd., or equal to a quarter of that of the first plate. In calculating the time of the fall by the same method as for the plate of 1·196 sq. yd., and by means of the same formula

$$R = \left\{0{\cdot}06638\,\text{lb.} + 0{\cdot}1295\,V^2 + 0{\cdot}276\,\frac{v}{t}\right\} A\ \text{yd.},$$

he found between the results of observation and those of calculation a coincidence quite sufficient to permit him to conclude that, between the extended limits in which he had operated, the resistance of the air is proportional to the extent of the surfaces. The temperature and barometric pressure were sensibly the same as in the experiments above referred to.

Comparison of Times and Spaces described in the Fall of a Plate of 0·299 Sq. Yd. Surface, from Observation and Calculation.

| Spaces described. | Duration. | | Spaces described. | Duration. | | Spaces described. | Duration. | |
|---|---|---|---|---|---|---|---|---|
| | Observed. | Calculated. | | Observed. | Calculated. | | Observed. | Calculated. |
| yds. | seconds. | seconds. | yds. | seconds. | seconds. | yds. | seconds. | seconds. |
| 0·0995 | 0·174 | 0·173 | 0·8322 | 0·490 | 0·485 | 4·809 | 1·240 | 1·215 |
| 0·2001 | 0·246 | 0·242 | 0·9000 | 0·519 | 0·515 | 5·997 | 1·361 | 1·330 |
| 0·2996 | 0·301 | 0·297 | 0·9995 | 0·547 | 0·543 | 6·997 | 1·476 | 1·412 |
| 0·4002 | 0·356 | 0·343 | 1·993 | 0·775 | 0·767 | 7·996 | 1·586 | 1·527 |
| 0·4811 | 0·387 | 0·384 | 2·998 | 0·951 | 0·939 | 8·996 | 1·693 | 1·646 |
| 0·5993 | 0·425 | 0·420 | 3·998 | 1·102 | 1·085 | 9·546 | 1·799 | 1·738 |
| 0·6999 | 0·460 | 0·454 | | | | | | |

*Consequence of these Results.*—We see by this Table that the calculated times of the falls are sensibly the same, though a trifle less than the observed times, which shows that if the coefficient of resistance varies with the extent of surface, it tends to diminish with the diminution of surface, rather than to increase, as some authors have concluded from experiments made by observation of the motion of rotation.

In recapitulating, we may, without fear of notable error, admit in practice that the resistance of the air is proportional to the extent of the surfaces.

*Experiments upon Parachutes.*—One of the most useful questions among our researches upon the resistance of air which our means of observation enabled us to resolve, was an exact determination of the resistance experienced by parachutes. Their concave form causing, with the same surface, a marked increase of resistance, it was easy, in this case, to obtain a uniform motion of descent, which was indicated by the curve representing the law of motion, which in this case degenerated into a straight line, whose inclination furnished the value of the uniform velocity.

The parachute employed was composed of a frame of whalebones, disposed into four equidistant meridian planes, fastened upon a common rod, and strengthened by stays. This frame was covered with taffeta, strongly stretched, and it was suspended upon a rod, at the lower part of which was attached the additional weights.

The exterior diameter of the parachute was 1·461 yd. measured perpendicularly from the sides of the polygon, and 1·312 yd. measured between the nearest points of the arcs formed by the rim. Its perpendicular projection to the direction of motion varied from 1·433 sq. yd. to 1·444 sq. yd. of surface. The versed sine of curvature of this parachute was 1·41 foot to the plane of the ends of the whalebones.

A discussion of the experiments in which the velocity was uniform has shown that the resistance of the air to the motion of this parachute could also be represented by an expression composed of two terms, and that it was equal to 1·936 times that of a plane of the same surface, that is to say, nearly double.

It follows, from this, that it may be expressed by the formula

$$\text{R} = 1{\cdot}936\ \text{A sq. yd.}\ [0{\cdot}06638\ \text{lb.} + 0{\cdot}1295\ \text{V}^2\ \text{yd.}] = \text{A sq. yd.}\ (0{\cdot}1285\ \text{lb.} + 0{\cdot}2507\ \text{V}^2),$$

for units of yards of surface and velocity, at the ordinary density and temperature of the air.

*Case where the Parachute presents its Convexity to the Air.*—In reversing the parachute, and causing it to descend with its convex surface downwards, a much less resistance was found, and equal 0·763 of that of the plane surface with the same area. So that in this case the resistance is represented by the formula

$$\text{R} = 0{\cdot}768\ \text{A sq. yd.}\ (0{\cdot}06638\ \text{lb.} + 0{\cdot}1295\ \text{V}^2) = \text{A}\ (0{\cdot}0509\ \text{lb.} + 0{\cdot}0994\ \text{V}^2).$$

We see by this that the resistance of the same body varies in the ratio of 1·936 to 0·768, or from 2·5 to 1, according as it presents to the air its concavity or convexity.

*Case where the Motion of the Parachute was Accelerated.*—In this expression of resistance we also admit the necessity of introducing a term dependent upon the acceleration of motion $\frac{v}{t}$, and this expression for the parachute employed is

$$\text{R} = \text{A}\left(0{\cdot}1290\ \text{lb.} + 0{\cdot}2513\ \text{V}^2 + 0{\cdot}2394\ \frac{v}{t}\right),$$

in units of yards for area and velocity.

A comparison of the observed times of the fall with those deduced from this formula has shown that it represents the circumstances of motion with all desirable accuracy.

*Resistance to the Motion of Inclined Planes in Air.*—These experiments were made by means analogous to those above described, by causing to descend two jointed planes, 1·0963 yd. long by 0·5486 yd. wide, whose angles were varied, at intervals of 5°, from 5° up to 180°, where they form a single plane. The results regularly observed from 180° to 130° have shown that the resistance

decreases proportionally with the angles, so that, calling $a$ the angle of one of the planes with the direction of motion, the resistance was expressed for uniform motion by the formula

$$R = \frac{a}{90} A\,(0{\cdot}06638\text{ lb.} + 0{\cdot}1295\,V^2),\text{ in units of yards.}$$

A comparison of the observed resistance with those calculated by this formula show a satisfactory agreement.

COMPARISON BETWEEN THE OBSERVED AND CALCULATED RESISTANCES, FOR DIFFERENTLY INCLINED PLANES.

| Angles formed by each of the Planes with the Direction of Motion. | Resistances in the ratio to those of a Plane perpendicular to the Direction of Motion. | | Angles formed by each of the Planes with the Direction of Motion. | Resistances in the ratio to those of a Plane perpendicular to the Direction of Motion. | |
|---|---|---|---|---|---|
| | Observed. | Calculated. | | Observed. | Calculated. |
| 90° | 1·0000 | 1·000 | 77°·5 | 0·846 | 0·861 |
| 87·5 | 0·996 | 0·972 | 70· | 0·773 | 0 778 |
| 82·5 | 0·865 | 0·917 | 67·5 | 0·737 | 0·750 |
| 80· | 0·856 | 0·889 | 65· | 0·728 | 0 722 |

It should be remarked that these results relate to the case of two equal and jointed planes, moved in the air, with the edge of intersection in front, and are by no means applicable to the case of isolated planes.

The law of the variation of the resistance proportionally to the angles is also that which these experimental philosophers found for water, in operating upon cones of different acutenes.

*General Conclusions from the Experiments at Metz.*—In conclusion, the reported experiments which have been made with chronometric mechanism, giving the times, to nearly some thousandths of seconds, and the velocities acquired at any instant nearly to a hundredth, in observing the law of descent in air of different sized plates, of two plates inclined towards each other, and that of a wheel with wings, for which the velocities have not exceeded from 29 to 33 feet a-second, have conducted us to the following conclusions:—

1st. In the uniform motion of a body in air, the resistance experienced is proportional to the extent of its surface, and to another factor composed of two terms, the one constant and the other proportional to the square of the velocity.

As it was easily foreseen that the number of molecules of the air shocked by the displacement of the body must increase in the same ratio with its density, the general expression of the resistance should contain a factor relative to this density; so that calling $d$ the density of the air at the temperature and pressure observed, and $d_1$ its density at 50° (Fah.) and at 76 centigrades (or 29·92 inches) of barometric pressure, and preserving the preceding notations, this resistance is represented by the following formulæ:

Thin plates perpendicular to the direction of motion $R = A\frac{d}{d_1}\left\{0{\cdot}066\text{ lb.} + 0{\cdot}199\,V^2\right\}$

Parachutes .. .. .. .. .. .. .. .. .. $R = A\frac{d}{d_1}\left\{0{\cdot}129\text{ lb.} + 0{\cdot}251\,V^2\right\}$

Parachutes reversed .. .. .. .. .. .. .. $R = A\frac{d}{d_1}\left\{0{\cdot}031\text{ lb.} + 0{\cdot}994\,V^2\right\}$

Two jointed plates, inclined towards each other .. $R = A\frac{d}{d_1}\frac{a}{90}\left\{0{\cdot}066\text{ lb.} + 0{\cdot}129\,V^2\right\}$

The wings of a fan-wheel .. .. .. .. .. .. $R = A\frac{d}{d_1}\left\{0{\cdot}08002\text{ lb.} + 0{\cdot}1545\,V^2\right\}$

It may be observed that this last formula accords in a satisfactory manner with the results of M. Thibault's experiments.

2nd. In accelerated motion we must add to the preceding expression a term proportional to the acceleration of motion, and the resistance is then represented by the following formulæ:

Thin plates perpendicular to the direction of motion $R = A\frac{d}{d_1}\left\{0{\cdot}066\text{ lb.} + 0{\cdot}129\,V^2 + 0{\cdot}276\,\frac{V}{g}\right\}$

Parachutes .. .. .. .. .. .. .. .. .. $R = A\frac{d}{d_1}\left\{0{\cdot}128\text{ lb.} + 0{\cdot}251\,V^2 + 0{\cdot}2391\,\frac{V}{g}\right\}$

With respect to the various modes of ascertaining the velocities of currents of air in mines, in order to determine the quantities circulating in a given time, we extract the following, on the nature and use of anemometers, from a paper by John J. Atkinson and John Daglish, published in the 'Transactions of the North of England Institute of Mining Engineers':—

In the ventilation of mines, great advantages are well known to arise from dividing the air into a series of currents or splits; and its proper distribution amongst these is an object of very great importance, because upon it depends, to a certain extent, not only the actual amount of the gross quantity that will be put into circulation, in a given time, by any ventilating power that may be employed, but also the relative degrees of safety and salubrity that will prevail in the different districts into which the mine is divided.

In order to effect this distribution of the air in such a manner as to obtain the most efficient general ventilation, and, at the same time, to allot to each district or split its proper share or proportion of the whole, it is essential to have some satisfactory mode of ascertaining the velocities of the currents, and the quantities of air circulating in each of the splits in the unit of time.

The various methods that have been employed for this purpose may be divided into three groups.

*First.*—By travelling at the same velocity as the current, and noting the distance passed over in a unit of time.

*Second.*—Determining from observation the rate at which small floating particles are carried along by the current, and assuming their velocities to be identical with that of the air-current itself. Smoke from exploded gunpowder, burning turpentine or amadou, small pieces of down, and small balloons filled with hydrogen, have been all more or less employed for this purpose.

*Third.*—By using anemometers, or apparatus of various forms; and these may be divided into three classes:—(*a*) Anemometers having vanes or wands, made to *revolve* by the current of air impinging upon them, the rate at which they revolve being indicated by pointers on dials forming a part of the instrument—the pointers being made to revolve by means of wheels connecting them with the axis of the vanes or wands. The anemometers of Combes, Biram, Whewel, Osler, and Robinson, are instances of this class of instruments now in use in this country, all of which require a correction for friction. (*b*) Instruments which are affected by the *force* or impulse of the wind, without being subjected to any continuous revolving motion, such as Dr. Lind's, Henaut's, Bougier's, and Dickinson's anemometers. (*c*) Anemometers of a more complex character, such as Leslie's.

*First Group.*—Perhaps the primitive mode of ascertaining the velocity of currents of air in mines was that of choosing a part of the gallery forming the air-way having as uniform sectional dimensions as could be found, and after measuring off a distance of 100 to 150 yds. in length, taking a lighted candle and walking in the direction of the current, holding the flame in such a position as to be fully exposed to the influence of the current, but taking care to walk at the particular rate required, to cause the flame to burn in an upright position, without being deflected from the vertical, either by the current or by the progress of the person carrying it. The time required to traverse the distance measured off, being noted by a seconds' watch, enabled the average rate of walking to be determined; and the average rate so found, from three or four trials, was assumed to be the velocity of the air-current; and this, multiplied by the average sectional area of the part of the air-way selected for the experiment, was taken to represent the quantity of air passing in the unit of time. Formerly, when this mode of measuring the air in mines was in use, it would afford a close approximation to the truth; but, with the ventilation now existing in many of our large mines, it would not be practicable to walk as quickly as the currents travel in the principal splits; and running is not a sufficiently steady pace. One of the objections to this, as well as to all other methods that require a considerable distance to be traversed, over which to observe the velocity, is the difficulty of obtaining a gallery of equal area throughout, over a sufficient distance; but in cases where this is attainable, this method admits of great accuracy for velocities up to 400 feet per minute; Atkinson and Daglish state that they have been able to obtain as accurate results by this method as by any other, as can be seen by referring to Table I. and Fig. 149. In Fig. 149, and in the other figures employed for the like purpose, the bent or crooked lines are obtained by taking the *actual* velocities of the air-currents (ascertained as hereafter described), and the revolutions of the anemometer, or other *indicated* velocities, as co-ordinates. If the indicated velocity were the same as the actual velocity, a line drawn through the points where they would intersect each other in the diagrams, would exactly coincide with the simple straight diagonal; but as the one exceeds the other, so the crooked lines drawn through their points of intersection depart more or less from the diagonal.

The close approximation of this line to the diagonal shows that great accuracy can be attained by walking with a lighted candle. It ought, however, to be mentioned that the place where the experiments were made was in all respects suitable, and specially adapted for the purpose, being perfectly level, and of an accurately uniform sectional area throughout the whole distance of 200 feet.

*Second Group.*—One of the principal of the second group of modes employed for the measurement of air consists in observing the velocity of the smoke from an exploded charge of gunpowder in a part of the gallery of nearly uniform sectional area; and this, until recently, was the means most generally adopted in the coal mines of this country for ascertaining the velocity of air-currents; and although it has of late been largely superseded by the use of Benjamin Biram's anemometer, the practice is still in considerable use, and, so far as regards shaft velocities, remains the only method. It is, therefore, desirable to ascertain how far the results obtained by this and similar methods of measuring air-currents can be relied upon for accuracy, and to investigate the various sources of error connected with them, with a view of either avoiding or making proper allowances for their effects, so far as may be practicable.

The sudden explosion of gunpowder in the confined passages of mines produces several effects, which tend to cause inaccuracies in the results obtained by noting the passage of the smoke as an index of the velocity of the current.

Experiments prove (as indeed might have been anticipated, considering the small quantities of gunpowder used) that in general neither the increase of bulk due to the introduction into the current of the *products of combustion*, nor that due to the *elevation of temperature*, have any appreciable effect on its velocity. But other experiments show that the *force of the explosion*, when a considerable quantity of gunpowder is used in a feeble current, gives an impulse to the current, and creates a velocity in excess of the normal one. A revolving anemometer was placed in an air-passage traversed by a feeble current, so regulated as to be just strong enough to produce thirty revolutions of the instrument a-minute. The explosion of a cubic inch of gunpowder at a distance

of 70 feet did not in any way affect the instrument; but when the charge of gunpowder was increased to 20 cubic inches, the explosion caused a sudden and violent increase of its rate of revolving, acting as a temporary impulse, the revolutions very quickly decreasing to the original number again. The same effect is also clearly shown in the second series of experiments, page 77. The amount of error arising from this source, and which tends to *increase* the apparent velocity, depends on the quantity of gunpowder used, the sectional area of the air-way, and the velocity of the current,—increasing with the quantity of gunpowder employed, but decreasing as the sectional area of the air-way and the velocity of the current are increased, so that the explosion of a large quantity of gunpowder in a feeble current of air passing over a short distance in a gallery of small sectional area will be attended with the greatest errors; but as, under the ordinary conditions of the currents and air-ways of mines, 1 cubic inch of gunpowder does not give rise to any sensible error from the cause alluded to, and as it affords sufficient smoke to be readily observable at a distance of 200 feet, that quantity has been adopted as a standard, and used in the experiments made by Atkinson and Daglish.

It appears to be very desirable that a standard quantity of gunpowder should be employed in all cases, whether in the ordinary measurement of air or in conducting experiments, to enable comparisons to be made, as any variation in this respect will give rise to discrepant results.

If a charge of gunpowder be exploded in an air-current, and the velocity of its smoke be timed over a series of consecutive and equal distances in an uniform air-way, it will be found to be apparently most rapid near the point of ignition, and to decrease gradually as it flies to a greater distance from that point. This is a most serious source of error, and may be regarded as fatal to the accuracy of this method of determining the velocity of a current of air.

The following experiments, selected from many others giving similar results, establish what has been just stated.

The charge in each of these experiments was 1 cubic inch of gunpowder, which was exploded 10 feet to the windward of the commencement of the first space, or interval of 25 feet, and the time was noted when the smoke reached the commencement and also the end of each of the two intervals of 25 feet, into which the total distance of 50 feet was divided.

EQUAL QUANTITIES OF GUNPOWDER AT DIFFERENT VELOCITIES.

| Time in passing over First Interval of 25 feet. | Time in passing over Second Interval of 25 feet. | Total Time. | Average Velocity of the Air-current, as indicated by the Smoke. |
|---|---|---|---|
| 15″ | 21″ | 36″ | 83 feet a-minute. |
| 12½″ | 15½″ | 28″ | 107 " |
| 6½″ | 9″ | 15½″ | 193 " |
| 5″ | 5½″ | 10½″ | 285 " |

In the above experiment it will be noticed that in all cases the time occupied in passing over the second interval is greater than that occupied in passing over the first; and it is further observable that this difference decreases as the velocity of the air increases. At the low velocity of 83 feet per minute the times are 15″ and 21″, being a difference of 40 per cent. of the lesser time; whilst at the higher velocity of 285 feet a-minute, the difference between 5″ and 5½″ only amounts to 10 per cent.

The charge of gunpowder, in the two following series of experiments, was varied in quantity, and exploded 20 feet to the windward of the first interval; the time being noted, as before, when the smoke reached the commencement and also the end of each of the two intervals of 50 feet.

DIFFERENT QUANTITIES OF GUNPOWDER AND EQUAL VELOCITIES

*First Series.*

| Quantity of Gunpowder. Cubic Inches. | Time in passing over First Interval of 50 feet. | Time in passing over Second Interval of 50 feet. | Total Time. | Average Velocity of Air-current, as indicated by the Smoke, in feet a-minute (presumed average). |
|---|---|---|---|---|
| 1 | 37″ | 45″ | 82″ | 75 |
| 4 | 27″ | 35″ | 62″ | .. |
| 20 | 15″ | 24″ | 39″ | .. |

*Second Series.*

| | | | | |
|---|---|---|---|---|
| 1 | 5″ | 5″ | 10″ | 600 |
| 4 | 5″ | 5″ | 10″ | .. |
| 20 | 4″ | 5″ | 9½″ | .. |

It will be observed in these experiments:—1st. That in a slow current (75 feet a-minute), with 20 cubic inches of gunpowder, the time occupied by the smoke in passing over the second interval of 50 feet was 60 per cent. more than it occupied in passing over the first interval of 50 feet, showing that the *apparent* velocity gradually decreased. These experiments further show, that this gradual loss of velocity is greatest where the charge of powder employed is greatest. 2nd. That the apparent velocity, and, therefore, the apparent quantity of air, is more than doubled (being in the proportion of eighty-two to thirty-nine) with the low velocity, by using 20 cubic inches of gunpowder instead of 1 inch. 3rd. That these discrepancies are by far the greatest at low velocities, and are hardly apparent at high velocities, as will be seen by the *second series*.

The smoke resulting from the explosion of gunpowder is not of the same density as the air-current. This has been observed by previous experimentists, and has been confirmed by Atkinson

and Daglish, by substituting turpentine smoke, which can be observed at a distance of 50 feet, but which dissipates, and cannot be accurately observed at 100 feet.

| One Cubic Inch Gunpowder. | | | | | | Turpentine. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Interval of 25 feet. | | Second Interval of 25 feet. | | Total. | | First Interval of 25 feet. | | Second Interval of 25 feet. | | Total. | |
| 17 | + | 21 | = | 38 | .. .. | 11 | + | 14 | = | 25 | |
| 13½ | + | 16½ | = | 30 | .. .. | 10 | + | 12 | = | 22 | |
| 7 | + | 9 | = | 16 | .. .. | 8 | + | 8 | = | 16 | |

It will be noticed that, whilst gunpowder smoke required 38', 30", and 16" respectively to travel a distance of 50 feet, in a current having the same velocity, turpentine smoke required only 25", 22", and 16". But it may be observed that experiments made with turpentine smoke are very unsatisfactory. The turpentine cannot, like gunpowder, be ignited in a large quantity simultaneously, but resembles more the ignition of a train of gunpowder; added to this, the resulting smoke is very difficult to discern, and is soon dissipated.

Experimentists who have written on this subject have also noticed another source of error in all currents, especially in the more feeble, in the eddies and streams of varying velocity which almost always exist; and when any small particles or light bodies are introduced into the currents, a part of them get into the axis of greatest velocity, and give a result higher than the average; other portions fly too slow; and even on the average of the first and last particles traversing the distance, the results are too low.

Similar remarks are applicable to the use of smoke; at least Mons. Jochams ('Annals des Travaux Publics de Belgique,' vol. ix.) came to these conclusions on comparing the results of his experiments by these modes with the corresponding and simultaneous observations made with Combes' anemometer. The results of his experiments, indicating the distances traversed per second by the different agents, are given in the following tabulated form:

| | Velocities deduced from Mons. Combes' Anemometer. | Velocities of the Current of Air observed with | | | | Down. |
|---|---|---|---|---|---|---|
| | | Powder Smoke. | | Amadou Smoke. | | |
| | | First of Smoke. | Average of Smoke. | First of Smoke. | Average of Smoke. | |
| Mètres .. .. | 4·84 | .. | .. | .. | .. | 4·31 |
| „ .. .. | 1·53 | 1·67 | 1·25 | 1·56 | 1·19 | |
| „ .. .. | 2·34 | 2·78 | 2·00 | 2·50 | 2·00 | |

In reference to the down especially, if it got out of the axis of the air-way where the most rapid current prevailed, it adhered to the damp walls of the gallery, and was, consequently, greatly retarded.

The various sources of error connected with the use of gunpowder smoke are given in the following tabular form:—

Causes of Error in Experimenting on the Velocity of Air-Currents in Mines, by means of Gunpowder Smoke.

| *Cause.* | *Effect.* |
|---|---|
| 1.—The expansion of the whole column of air, by the addition to it of the results of the combustion of gunpowder, and by the heat developed (*of slight magnitude*). | Tending to *increase* apparent velocity owing to two causes, *viz.*:— 1.—The conversion of a small portion of solid gunpowder into gas. 2.—The further expansion of this, owing to the high temperature of ignition. |
| 2.—The explosive force of gunpowder (*of considerable magnitude*). | Tending to *increase* the apparent velocity, and can be avoided with care. |
| 3.—Diffusion or deposition of the smoke. | Tending to *decrease* very considerably the apparent velocity. |
| 4.—Eddies and currents. 5.—The density of the smoke. | Giving rise to serious irregularities, materially affecting the accuracy of the results. |

*Precautions to be used in Experimenting with Gunpowder Smoke.*—By the use of fixed quantities and distances, and the avoidance of extreme velocities, an *approximation* to accuracy in the measurement of air-currents by gunpowder smoke may be attained; and the numerous experiments made by Atkinson and Daglish suggest the following precautions as being necessary:—

1st. Always to use 1 cubic inch of gunpowder as a standard.

2nd. The *velocity* of the current never to be less than 100 feet a-minute, nor to exceed 500 feet a-minute. In order to attain this, a gallery of such area must be selected as will afford this velocity of current.

3rd. The *time* not to be less than twelve seconds, nor to exceed thirty seconds.

4th. To explode the gunpowder 10 feet to the windward of the first mark.

Therefore, in slow currents of from 100 to 250 feet per minute velocity, the distance to be taken over which the smoke passes will be 50 feet; and for the higher velocities of from 250 to 500 feet, the distance will be increased to 100 feet.

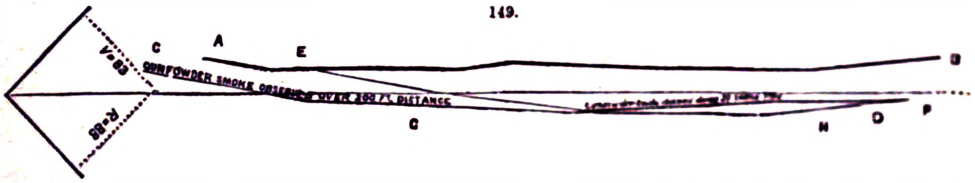
The following Table of Experiments, made by timing gunpowder smoke, by walking so as to keep the flame of an exposed light in a vertical position, and by the use of a Biram's anemometer respectively, is given with a view of showing the comparative degrees of accuracy of these different modes of measuring currents of air; and the results are graphically exhibited in Fig. 149.

TABLE I.—EXPERIMENTS MADE WITH GUNPOWDER SMOKE, WALKING, AND AN ANEMOMETER (BIRAM'S 6-INCH) IN THE SAME CURRENT OF AIR.

| | Gunpowder Smoke. | | | Walking. | Anemometer. | |
|---|---|---|---|---|---|---|
| | Equal Distances. | | Equal Times. | 200 feet | Recorded Revolutions = R. | True Velocities calculated. = ·97 R + 40 nearly |
| | 50 feet. | 200 feet. | 20 seconds. | | | |
| | A B. | C D. | E F. | G H. | | |
| | Feet a-minute. | Feet a-minute. | Feet a-minute. | Feet a-minute. | Revolutions. | Feet a-minute. |
| 1 | 125 | 100 | .. | 88 | 44 | 83 |
| 2 | 158 | 162 | .. | .. | 90 | 127 |
| 3 | 166 | .. | 171· | 162 | 103 | 140 |
| 4 | 250 | 214 | 228 | .. | 188 | 222 |
| 5 | 285 | .. | .. | .. | 220 | 253 |
| 6 | 300 | 255 | 263 | 255 | 233 | 266 |
| 7 | 353 | 307 | 307 | 307 | 293 | 324 |
| 8 | 461 | 413 | 428 | 413 | 407 | 435 |
| 9 | 545 | 500 | 502 | 500 | 482 | 507 |

*Explanation of Table I. and Fig.* 149.—A B column. In these experiments the time during which the powder smoke travelled a distance of 50 feet was observed, and from it the velocity per minute calculated; thus, in the first experiment the time so occupied was 24", indicating a velocity of 125 feet per minute; this is the ordinary mode of finding the velocity of air by powder smoke.

149.




It will be observed that, owing to the distance travelled over by the smoke being short, the velocities of the smoke are in excess of the true velocities of the air.

In column C D, the distance over which the time of the powder smoke is noted is 200 feet instead of 50 feet; and it will be observed that the apparent velocities here are less than the true ones, excepting in the two first experiments, where the contrary result is due probably to the explosive force of the gunpowder in a feeble current.

Column E F.—Experiments made by using "equal times" instead of "equal distances," and varying the distance, so that in each experiment the *time of observation* was as nearly as possible the same.

Column G H.—Experiments made by walking 200 feet with a lighted candle, and noting the time, and calculating velocity per minute therefrom.

Anemometer columns give the velocity as recorded on the dial of a Biram's anemometer. These readings require correction by the formula, for this instrument nearly, V = ·97 R + 40,

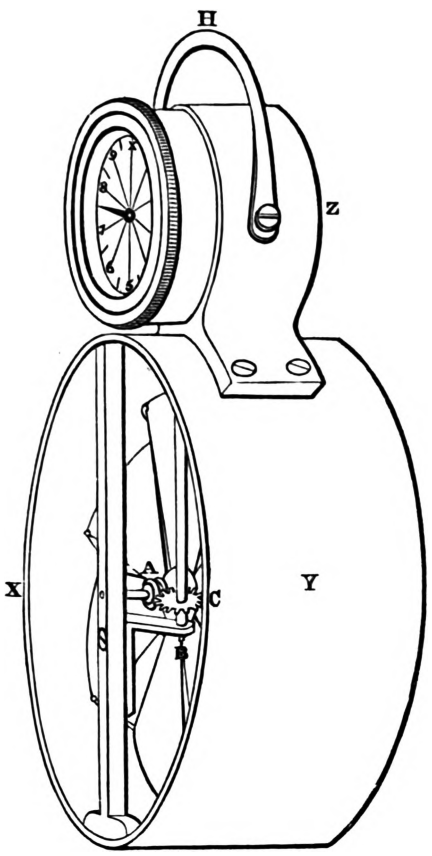
where V = the velocity of the air-current in feet a-minute;

and R = the revolutions of the anemometer, as shown by the index on its dial, in the same time.

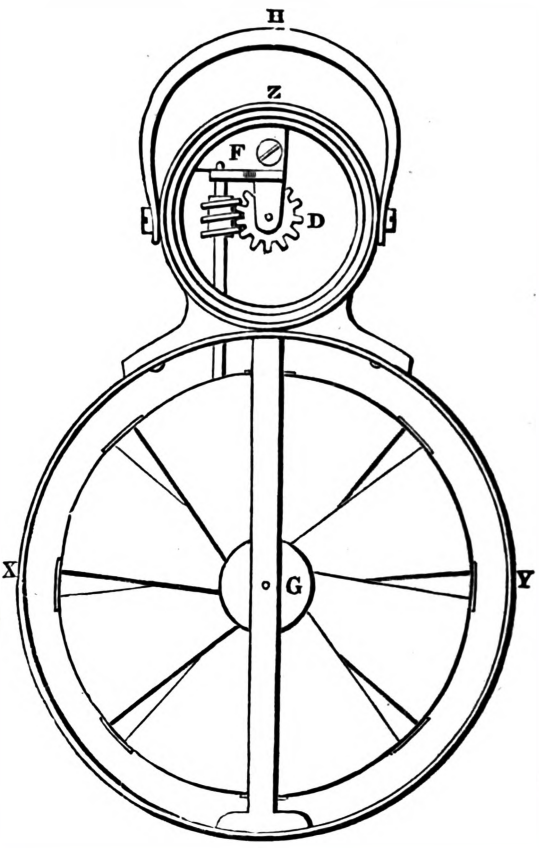
These experiments were conducted with the greatest care, in a gallery of a mine specially adapted for the purpose, by being made perfectly level, and of uniform sectional area; during the experiments the velocity was kept as constant as practicable throughout, by keeping the water-gauge of that part of the mine at a uniform height. The observations were taken with a large seconds' watch, specially adapted to this purpose, and all experiments were repeated until a correct average could be obtained; but even under these circumstances, which in general will not prevail for ordinary measurements in mines, great discrepancies are observable between the results obtained by timing smoke over equal distances, and those obtained either by timing smoke during equal times, or over equal distances of different lengths. Doubtless such an empirical rule could be found for so regulating the distance to be traversed, the amount of powder to be exploded, and the duration of the experiments, as that with great care nearly accurate results could be obtained: still the difficulty of obtaining galleries fully adapted for the purpose, by their uniformity of sectional area, &c., and the numerous chances of error in observation are so great, that it is most desirable that there should be some more ready and accurate mode of ascertaining the velocities of currents of air; anemometers of various constructions have of late been more or less employed for the purpose, and it is therefore important to ascertain how far the indications of such instruments can be relied upon for accuracy.

*Revolving Anemometers.*—The anemometer most generally used in the coal mines of England is that invented by Benjamin Biram, shown in Figs. 150, 151, 152. It consists of a series of vanes,

150.

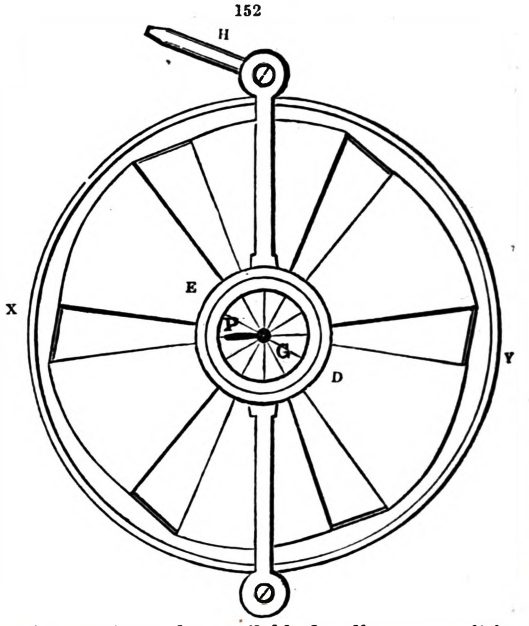



151.




D, E, Fig. 152, which resolve with the action of the air-current—the number of revolutions, or rather numbers proportional to the revolutions, being registered by pointers, P, on the face of a dial forming a part of the instrument itself. It is made of three sizes, 4, 6, and 12 inches; is very portable; and is not, with proper care, liable to get out of order, especially the smaller size. A certain force of current is required to overcome the friction, and put the instrument into motion. The plate spur-wheel C, Fig. 150, as it moves in a horizontal plane, relieves the step B, Fig. 150, from undue pressure, and thus tends to lessen the amount of friction. Some of these instruments will continue to revolve in a current as low as 30 feet a-minute; but with most of them a velocity of about 50 feet is required.

152




Every one who has occasion to use this anemometer should be aware that it does not register the actual velocity of the air, especially in feeble air-currents, nor yet the number of revolutions of the wands, but only a number proportional to the latter; and although it is of great value, as indicating an increase or decrease in the velocity from time to time, such as the periodical variations in any particular current, it is of comparatively little value, *as generally used*, for ascertaining real velocities, such, for instance, as occur in changing or splitting air-currents, when it is of great importance to know the actual quantities. To obtain with this instrument accurate results, available for all purposes, it is necessary, as with Combes' anemometer, to apply a formula to its recorded revolutions, or rather to the number indicated by the index, in order to ascertain the actual velocity of any current; each particular instrument requiring special experiments to be made with it, in order to determine the

value of the constants required to be employed in the formula. These constants remain the same for the same instrument, so long as it remains in the same condition, and are independent of the velocities of the currents of air in which it is employed. However, it is necessary to state that these adjustments are carefully made by the principal manufacturer, John Davis, optician, Derby, who is a man of considerable mechanical skill.

In anemometers made like that shown in Fig. 152, the mechanism, dial, and pointers are placed in the centre. The arrangement does not essentially differ from that shown in Figs. 150, 151. X Y is the cylindrical case in which the fan-wheel revolves, supported by the upright bars G, S; H, handle by which the instrument is held.

In Figs. 150, 151, part of the mechanism is contained in a small box, Z, over the fan-wheel, which is thus allowed more play. A, F, are small, delicate axles, upon which are cut endless screws, A, F, which drive small wheels, C, D.

The registering apparatus is in front of the wheel, and consists of six small circles, marked respectively X, C, M, X M, C M, and M, the divisions on which denote units of the denominations of the respective circles; in other words, the X index in one revolution passes over its ten divisions, and registers (10 × 10), or 100 feet; the C index, in the same way, 1000 feet and so on up to 10 million feet; so that an observer has only to record the position of the several indices, at the first observation (by writing the lowest of the two figures on the respective circles between which the index points, in their proper order), and deduct the amount from their position at the second observation, to ascertain the velocity of the air which has passed during the interval. This, multiplied by the area in feet of the passage where the instrument is placed, will show the number of cubic feet which has passed during the same period.

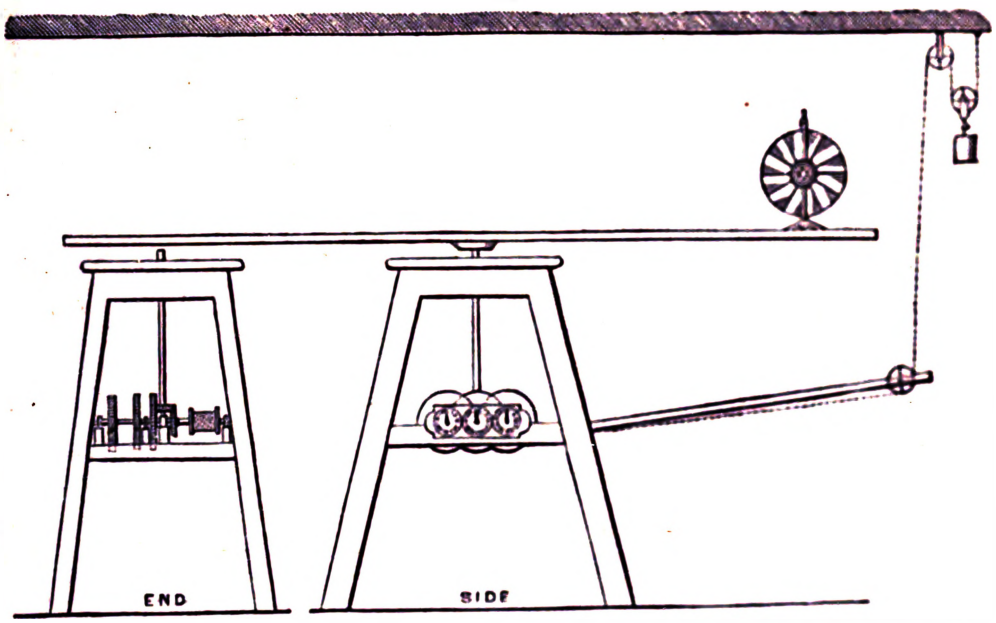
To ascertain the rate at which air is moving, proceed thus:—suppose 100 revolutions = 200 feet per minute.

88] 200 [2·27 miles an hour.

To obtain the constants of this formula, as applicable to any particular instrument, it is absolutely necessary, in making the experiments, to know correctly the true velocity, as a standard of comparison. As before explained, none of the ordinary modes employed for ascertaining the real velocities are reliable; Atkinson and Daglish, therefore, had a Whirling Machine constructed, the wand of which, in revolving, described a circle of 25 feet in circumference; the number of its revolutions being indicated by a pointer on a dial.

In the first instance, this Whirling Machine was turned by the hand, but as this did not give a sufficiently uniform velocity, a small drum, and a rope with a descending weight attached to it, was employed, to give motion to the machine; and worked thus it gave extremely accurate results; so far, at least, as regards the uniformity of its own velocity. By fixing the anemometer on the end of the wand, the velocity with which it passes through the air can be ascertained and compared with the revolutions of the anemometer, as indicated on its dial. Fig. 153 represents this machine.

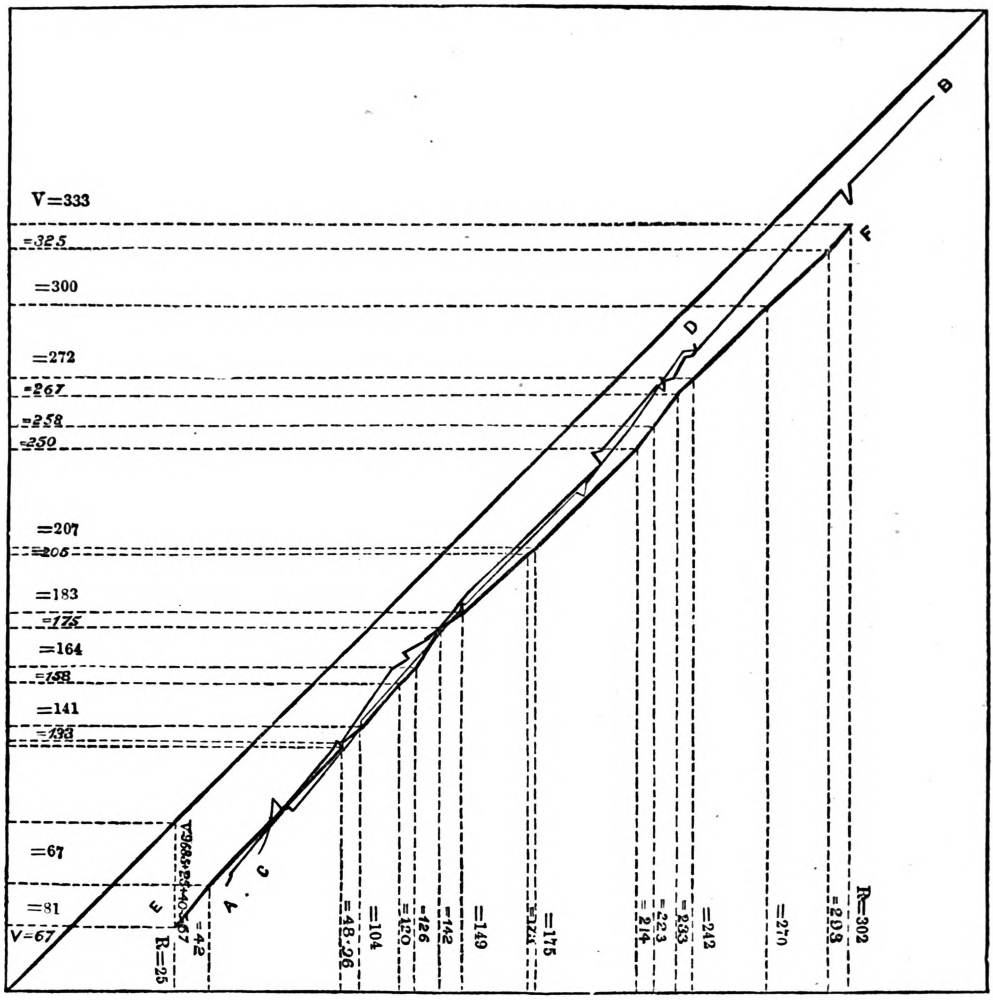
153.




It has been stated by some writers that there is a difference between the force or impulse of air moving upon a body at rest, and the resistance which a body moving through a still atmosphere meets with in its passage, supposing the velocity to be the same in each case; and besides this, the effect of a body moving in a circle, in a still atmosphere, may not be the same as when moving in a straight line. The experiments of Hutton and others appear, however, to indicate that the force of impact of a wind against a stationary body is always proportional to the resistance which a solid, moved through a still atmosphere, meets with at the same velocity.

*Comparison of Governors.*—The following experiments were made with the Whirling Machine, and the results are given both in a diagram, Fig. 154, and in a tabulated form, Table II.

154.




Scale 40 feet a-minute, half an inch.

In this diagram the different bent or crooked lines are drawn through the points found by taking the actual velocities of the anemometer through a still atmosphere, and the numbers indicated by the pointers of the anemometer as being passed over in the unit of time, as the co-ordinates of a line or curve in each series of experiments made at different velocities under the same conditions, and with the same anemometer. A sufficient number of the co-ordinates are transferred from Table II. to Fig. 154, to connect the Table with the Figure.

The anemometers at the commencement of the experiments were made to revolve by the Whirling Machine in a circle only 10 feet in circumference; but as the rate of revolution appeared to be somewhat irregular, a flat board, intended to regulate the motion and render it uniform, was fixed at the end of the revolving wand opposite to that at which the anemometer was fixed; and the experiments shown by the lines A B, C D, were made, the former with the regulating-board projecting downwards, and the latter with it projecting upwards, from the revolving wand.

The discrepancies between these lines are so slight, that the mere position of the regulating-board does not appear to have any sensible effect; the changes in the state of lubrication of the anemometer, and errors of observation, being sufficient to account for the slight differences that exist.

The line E F, in the same diagram, exhibits the results of certain experiments made with the same anemometer in the same sized circle, but without any flat board or governor on the wand; and as these experiments give results differing considerably from the two lines obtained with the governor on the wand, we infer that the governor really produces some effect.

As, however, all the three lines are sensibly straight, the inference is that the effect does not arise from any greater uniformity in the rate of motion with, than exists without, the board; because so long as the lines are straight, it follows that an average speed, however irregular, would, on the whole, give the same general results as a uniform speed equal to such average; and hence we infer that the governor only produces an effect that is disadvantageous, arising probably from disturbing the stillness of the atmosphere in which the experiments are conducted.

On these considerations we are led to reject the experiments made with the governors, and, so far, adopt those shown by the line E F, in which no governor was used.

This view was partly confirmed on using a longer wand, and causing the anemometers to revolve in a circle 25 feet in circumference, in lieu of one of only 10 feet in circumference; as, under these circumstances, the irregularity of the rate of revolution is much less apparent.

The results of the experiments give a straight line in the diagram, and lead to a formula of the form of $V = m R + a$, the same as arrived at by M. Combes, where V = velocity of air R = revolutions of anemometer, or rather the numbers indicated by its index, in the unit of time; and $m$ and $a$, constants, suited to the friction of the anemometer, the form of the vanes, and the density of the air.

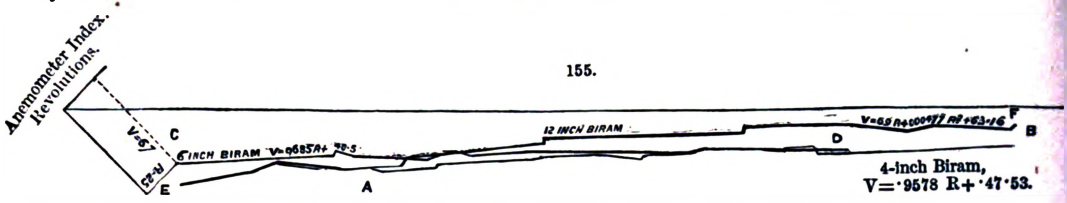
TABLE II.—EXPERIMENTS MADE WITH A 6-INCH BIRAM'S ANEMOMETER TO ASCERTAIN THE EFFECT OF PLACING A BOARD ON THE END OF THE WAND OF THE WHIRLING MACHINE, TO ACT AS A GOVERNOR, THE CIRCLE DESCRIBED BY THE WAND BEING 25 FEET IN CIRCUMFERENCE.

| | Without the Governor or Board. Line E F. | | | | | Board Upwards. Line A B. | | | | | Board Downwards. Line C D. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity. | | | Error. | | Velocity. | | | Error. | | Velocity. | | | Error. | |
| No of Experiment. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·9895 R + 40·6. | More. | Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by Index of Anemometer V = ·9197 R + 40·5. | More. | Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·9 R + 40·3. | More. | Less. |
| 1 | 25 | 67 | .. | .. | .. | 43 | 85 | .. | .. | .. | 56 | 99 | .. | .. | .. |
| 2 | 42 | 81 | 81 | .. | .. | 49 | 89 | .. | .. | .. | 65 | 104 | .. | .. | .. |
| 3 | 96 | 133 | .. | .. | .. | 50 | 89 | .. | .. | .. | 71 | 108 | 109 | 1 | .. |
| 4 | 97 | 133 | .. | .. | .. | 53 | 92 | .. | .. | .. | 72 | 113 | .. | .. | .. |
| 5 | 98 | 133 | .. | .. | .. | 53 | 92 | .. | .. | .. | 72 | 112 | .. | .. | .. |
| 6 | 104 | 141 | .. | .. | .. | 95 | 129 | .. | .. | .. | 75 | 106 | .. | .. | .. |
| 7 | 120 | 158 | 157 | .. | 1 | 97 | 131 | .. | .. | .. | 75 | 106 | .. | .. | .. |
| 8 | 126 | 164 | .. | .. | .. | 97 | 131 | 130 | .. | 1 | 107 | 142 | .. | .. | .. |
| 9 | 142 | 175 | .. | .. | .. | 98 | 131 | .. | .. | .. | 107 | 142 | .. | .. | .. |
| 10 | 149 | 183 | .. | .. | .. | 98 | 133 | .. | .. | .. | 107 | 142 | .. | .. | .. |
| 11 | 173 | 205 | 208 | 3 | .. | 127 | 156 | .. | .. | .. | 108 | 142 | 142 | .. | .. |
| 12 | 175 | 207 | .. | .. | .. | 128 | 156 | .. | .. | .. | 150 | 180 | .. | .. | .. |
| 13 | 214 | 250 | .. | .. | .. | 131 | 158 | 160 | 2 | .. | 152 | 181 | .. | .. | .. |
| 14 | 223 | 258 | .. | .. | .. | 132 | 158 | .. | .. | .. | 153 | 183 | .. | .. | .. |
| 15 | 233 | 267 | .. | .. | .. | 137 | 168 | .. | .. | .. | 153 | 183 | .. | .. | .. |
| 16 | 242 | 272 | .. | .. | .. | 137 | 168 | 167 | .. | 1 | 195 | 225 | .. | .. | .. |
| 17 | 270 | 300 | .. | .. | .. | 137 | 168 | .. | .. | .. | 196 | 223 | .. | .. | .. |
| 18 | 293 | 325 | .. | .. | .. | 140 | 171 | .. | .. | .. | 198 | 225 | .. | .. | .. |
| 19 | 302 | 333 | 333 | .. | .. | 140 | 171 | .. | .. | .. | 198 | 225 | 225 | .. | .. |
| 20 | .. | .. | .. | .. | .. | 141 | 172 | .. | .. | .. | 199 | 225 | .. | .. | .. |
| 21 | .. | .. | .. | .. | .. | 158 | 183 | .. | .. | .. | 223 | 248 | .. | .. | .. |
| 22 | .. | .. | .. | .. | .. | 208 | 233 | .. | .. | .. | 223 | 248 | .. | .. | .. |
| 23 | .. | .. | .. | .. | .. | 210 | 233 | .. | .. | .. | 252 | 267 | .. | .. | .. |
| 24 | .. | .. | .. | .. | .. | 211 | 235 | .. | .. | .. | 253 | 273 | .. | .. | .. |
| 25 | .. | .. | .. | .. | .. | 211 | 235 | .. | .. | .. | 256 | 273 | 275 | 2 | .. |
| 26 | .. | .. | .. | .. | .. | 236 | 260 | .. | .. | .. | .. | .. | .. | .. | .. |
| 27 | .. | .. | .. | .. | .. | 237 | 258 | .. | .. | .. | .. | .. | .. | .. | .. |
| 28 | .. | .. | .. | .. | .. | 238 | 260 | .. | .. | .. | .. | .. | .. | .. | .. |
| 29 | .. | .. | .. | .. | .. | 238 | 260 | .. | .. | .. | .. | .. | .. | .. | .. |
| 30 | .. | .. | .. | .. | .. | 239 | 260 | .. | .. | .. | .. | .. | .. | .. | .. |
| 31 | .. | .. | .. | .. | .. | 240 | 260 | .. | .. | .. | .. | .. | .. | .. | .. |
| 32 | .. | .. | .. | .. | .. | 242 | 264 | .. | .. | .. | .. | .. | .. | .. | .. |
| 33 | .. | .. | .. | .. | .. | 249 | 267 | .. | .. | .. | .. | .. | .. | .. | .. |
| 34 | .. | .. | .. | .. | .. | 250 | 269 | .. | .. | .. | .. | .. | .. | .. | .. |
| 35 | .. | .. | .. | .. | .. | 252 | 271 | .. | .. | .. | .. | .. | .. | .. | .. |
| 36 | .. | .. | .. | .. | .. | 256 | 275 | .. | .. | .. | .. | .. | .. | .. | .. |
| 37 | .. | .. | .. | .. | .. | 270 | 287 | .. | .. | .. | .. | .. | .. | .. | .. |
| 38 | .. | .. | .. | .. | .. | 313 | 333 | .. | .. | .. | .. | .. | .. | .. | .. |
| 39 | .. | .. | .. | .. | .. | 317 | 333 | .. | .. | .. | .. | .. | .. | .. | .. |
| 40 | .. | .. | .. | .. | .. | 317 | 329 | .. | .. | .. | .. | .. | .. | .. | .. |
| 41 | .. | .. | .. | .. | .. | 319 | 333 | .. | .. | .. | .. | .. | .. | .. | .. |
| 42 | .. | .. | .. | .. | .. | 320 | 333 | .. | .. | .. | .. | .. | .. | .. | .. |
| 43 | .. | .. | .. | .. | .. | 345 | 358 | .. | .. | .. | .. | .. | .. | .. | .. |
| 44 | .. | .. | .. | .. | .. | 355 | 367 | .. | .. | .. | .. | .. | .. | .. | .. |
| 45 | .. | .. | .. | .. | .. | 355 | 367 | 367 | .. | .. | .. | .. | .. | .. | .. |

The experiments represented by the line E F in the diagram are fairly represented by the formula V = ·9685 R + 40·5.

The rejected line A B, in this diagram represents experiments made with an anemometer revolving in a horizontal circle 25 feet in circumference, through a still atmosphere, with a governor-board 2 feet in area fixed upwards, at the contrary end of the wand to that on which the anemometer was fixed, and give rise to a similar formula, namely, V = ·9197 R + 40·5.

While the rejected line C D, represents experiments made under similar conditions with the same anemometer, excepting that the governor in this case was turned downward, and give V = ·9 R + 45·3; so that, on the whole, the use of the governor appears to increase the numbers indicated by the index of the anemometer, excepting, perhaps, at very low velocities.




The experiments from which this diagram was constructed are as follows:—

TABLE IV.—EXPERIMENTS MADE WITH THE THREE SIZES OF BIRAM'S ANEMOMETERS TO ASCERTAIN THE CONSTANTS *m* AND *a* IN THE FORMULA V = *m* R + *a* FOR EACH INSTRUMENT, THE TRUE VELOCITIES BEING ASCERTAINED BY PASSING THE ANEMOMETERS THROUGH A STILL ATMOSPHERE AT KNOWN VELOCITIES BY THE WHIRLING MACHINE, IN A CIRCLE OF 25 FEET IN CIRCUMFERENCE.

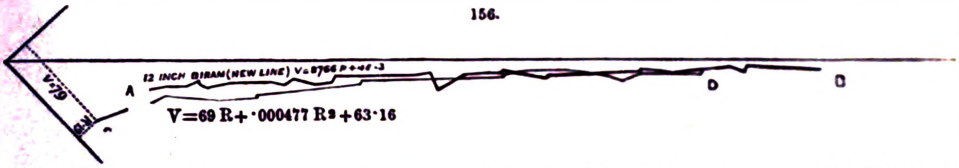
| No. of Experiment. | Line A B, 4-in. Anemometer. | | | | | Line C D, 6-in. Anemometer (same as E F, Fig. 154). | | | | | Line E F, 12-in. Anemometer (same as C D, 156, and A B, 158). | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity. | | | Error. | | Velocity. | | | Error. | | Velocity. | | | Error. | |
| | Number Indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·9578 R + 47·53. | More. | Less. | Number Indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·9685 R + 40·5. | More. | Less. | Number Indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·69 R + ·00477 R² + 63·16. | More. | Less. |
| 1 | 107 | 150 | 150 | .. | .. | .. | .. | .. | .. | .. | 19 | 79 | 78 | .. | 1 |
| 2 | 110 | 156 | .. | .. | .. | .. | .. | .. | .. | .. | 46 | 96 | .. | .. | .. |
| 3 | 132 | 175 | .. | .. | .. | .. | .. | .. | .. | .. | 55 | 102 | .. | .. | .. |
| 4 | 132 | 173 | .. | .. | .. | .. | .. | .. | .. | .. | 67 | 108 | .. | .. | .. |
| 5 | 142 | 183 | .. | .. | .. | .. | .. | .. | .. | .. | 93 | 137 | .. | .. | .. |
| 6 | 152 | 192 | 193 | 1 | .. | .. | .. | .. | .. | .. | 117 | 158 | .. | .. | .. |
| 7 | 167 | 206 | .. | .. | .. | .. | .. | .. | .. | .. | 119 | 158 | .. | .. | .. |
| 8 | 173 | 212 | .. | .. | .. | .. | .. | .. | .. | .. | 151 | 183 | .. | .. | .. |
| 9 | 180 | 217 | .. | .. | .. | .. | .. | .. | .. | .. | 186 | 208 | .. | .. | .. |
| 10 | 200 | 234 | .. | .. | .. | .. | .. | .. | .. | .. | 185 | 208 | .. | .. | .. |
| 11 | 203 | 242 | .. | .. | .. | .. | .. | .. | .. | .. | 215 | 236 | .. | .. | .. |
| 12 | 205 | 242 | 244 | 2 | .. | .. | .. | .. | .. | .. | 257 | 276 | .. | .. | .. |
| 13 | 209 | 247 | .. | .. | .. | .. | .. | .. | .. | .. | 267 | 283 | .. | .. | .. |
| 14 | 249 | 281 | .. | .. | .. | .. | .. | .. | .. | .. | 268 | 283 | .. | .. | .. |
| 15 | 250 | 283 | .. | .. | .. | .. | .. | .. | .. | .. | 288 | 300 | .. | .. | .. |
| 16 | 210 | 247 | .. | .. | .. | .. | .. | .. | .. | .. | 305 | 317 | 318 | 1 | .. |
| 17 | 275 | 306 | .. | .. | .. | .. | .. | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 18 | 273 | 306 | .. | .. | .. | .. | .. | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 19 | 287 | 317 | .. | .. | .. | .. | .. | .. | .. | .. | 327 | 342 | .. | .. | .. |
| 20 | 286 | 321 | .. | .. | .. | .. | .. | .. | .. | .. | 333 | 350 | .. | .. | .. |
| 21 | 337 | 371 | .. | .. | .. | .. | .. | .. | .. | .. | 345 | 358 | .. | .. | .. |
| 22 | 368 | 400 | 401 | 1 | .. | .. | .. | .. | .. | .. | 378 | 392 | 392 | .. | .. |
| 23 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 382 | 392 | .. | .. | .. |

*Comparison of Anemometers.*—Fig. 155 exhibits graphically the results of experiments made with three Biram's anemometers of the different sizes, on the Whirling Machine, in a circle of 25 feet in circumference, without any governor. We observe that, for the 4-inch and 6-inch anemometers, the lines are sensibly straight, and the formula consequently simple, and of the form previously indicated. With the 12-inch anemometer, however, the line is curved, and the formula complicated, and troublesome in consequence; and, although the friction of this large anemometer is somewhat greater than that of the smaller ones, the difference in this respect is trifling; even the large instrument would apparently be kept in motion by a velocity of 64 feet per minute, or little more than 1 foot per second: and as friction must be allowed for in all cases, its amount is of no great importance, within moderate limits. It is not very easy to account for the curvature of the line

given by the large instrument, when not observed in the smaller ones; may, however, arise from one of two causes, or possibly partly from both. The large instrument is moved sensibly quicker in the circle of revolution at its outer than at its inner extremity, while this difference of velocity in the two sides of the anemometer is less palpable in the smaller ones; and this difference may tend to cause all the instruments to depart from the straight line, but, from being less in amount with small instruments, may not be observable within the velocities attained in the experiments: or, apart from this cause, all such anemometers may give curved lines when plotted in this way, but perhaps quicker curves in large than small instruments; considerations as to strength, portability, comparative freedom from liability to derangement, and original cost, all appear to be favourable to the use of the 6-inch or 4-inch Biram anemometer, in preference to the 12-inch ones.

The constant multiplier, *m*, in these formulæ—which depends to some extent, for its amount, upon the spur-gear, and the arbitrary marks and numbers on the dial—is greatest on the 6-inch, and least in the 12-inch anemometer; while in the smallest, or 4-inch, it is intermediate; proving that it does not necessarily follow the size of the instrument, but really depends partly upon the conditions just mentioned.

156.




SECOND SET OF EXPERIMENTS, MADE WITH A BIRAM'S 12-INCH ANEMOMETER, WITH WHIRLING MACHINE, 25-FEET CIRCLE, FIG. 156, MADE TO CORROBORATE EXPERIMENTS, FIG. 155.

| A B (New Series). | | | | | | C D. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Velocity. | | | Error. | | Velocity. | | | Error. | |
| No. of Experiment. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·8766 R + ·0001428 R² + 35·65. | More. | Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·69 R + ·000477 R² + 63·16. | More. | Less. |
| 1 | 64 | 96 | .. | .. | .. | 19 | 79 | 78 | .. | 1 |
| 2 | 77 | 104 | .. | .. | .. | 46 | 96 | .. | .. | .. |
| 3 | 88 | 114 | 114 | .. | .. | 55 | 102 | .. | .. | .. |
| 4 | 93 | 118 | .. | .. | .. | 67 | 108 | .. | .. | .. |
| 5 | 94 | 121 | .. | .. | .. | 93 | 137 | .. | .. | .. |
| 6 | 95 | 123 | .. | .. | .. | 117 | 158 | .. | .. | .. |
| 7 | 110 | 133 | .. | .. | .. | 119 | 158 | .. | .. | .. |
| 8 | 134 | 156 | .. | .. | .. | 151 | 183 | .. | .. | .. |
| 9 | 136 | 158 | .. | .. | .. | 186 | 208 | .. | .. | .. |
| 10 | 143 | 167 | .. | .. | .. | 185 | 208 | .. | .. | .. |
| 11 | 143 | 167 | .. | .. | .. | 215 | 236 | .. | .. | .. |
| 12 | 150 | 167 | 170 | 3 | .. | 257 | 276 | .. | .. | .. |
| 13 | 161 | 185 | .. | .. | .. | 267 | 283 | .. | .. | .. |
| 14 | 170 | 192 | .. | .. | .. | 268 | 283 | .. | .. | .. |
| 15 | 173 | 192 | .. | .. | .. | 288 | 300 | .. | .. | .. |
| 16 | 175 | 192 | .. | .. | .. | 305 | 317 | 318 | 1 | .. |
| 17 | 216 | 233 | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 18 | 227 | 242 | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 19 | 244 | 258 | .. | .. | .. | 327 | 342 | .. | .. | .. |
| 20 | 262 | 275 | .. | .. | .. | 333 | 350 | .. | .. | .. |
| 21 | 269 | 283 | .. | .. | .. | 345 | 358 | .. | .. | .. |
| 22 | 272 | 283 | .. | .. | .. | 378 | 392 | 392 | .. | .. |
| 23 | 293 | 308 | .. | .. | .. | 382 | 392 | .. | .. | .. |
| 24 | 295 | 308 | .. | .. | .. | .. | .. | .. | .. | .. |
| 25 | 348 | 358 | .. | .. | .. | .. | .. | .. | .. | .. |
| 26 | 357 | 367 | .. | .. | .. | .. | .. | .. | .. | .. |
| 27 | 399 | 408 | .. | .. | .. | .. | .. | .. | .. | .. |
| 28 | 403 | 417 | .. | .. | .. | .. | .. | .. | .. | .. |
| 29 | 405 | 417 | .. | .. | .. | .. | .. | .. | .. | .. |
| 30 | 410 | 417 | 417 | .. | .. | .. | .. | .. | .. | .. |
| 31 | 424 | 433 | .. | .. | .. | .. | .. | .. | .. | .. |
| 32 | 448 | 458 | .. | .. | .. | .. | .. | .. | .. | .. |
| 33 | 224 | 250 | .. | .. | .. | .. | .. | .. | .. | .. |
| 34 | 346 | 358 | .. | .. | .. | .. | .. | .. | .. | .. |
| 35 | 362 | 375 | .. | .. | .. | .. | .. | .. | .. | .. |

*Comparison of Anemometers.*—Fig. 156. In consequence of the sensible difference in the formula required for the 12-inch, and for the 6-inch and 4-inch anemometers, as exhibited in Fig. 155,

another set of experiments were made to prove whether this was owing to the construction of the larger instrument, or to some error in observation in the previous experiments. The results are given in Fig. 156.

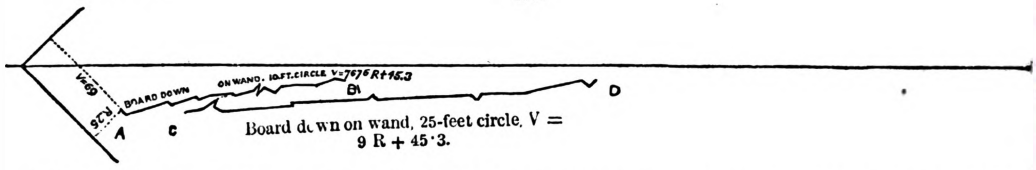
In this diagram two sets of experiments, made with the same 12-inch anemometer, at different times, by the Whirling Machine, with a circle 25 feet in circumference, are compared with each other.

The line C D is the same as the line E F of Fig. 155, and is a curve, as has been already stated; the line A B is also a curve, but approaches rather more nearly to a straight line, the friction being at the same time much smaller than in the same instrument tried in the experiments shown by Fig. 155, so that the friction does not appear to depend so much upon the size as upon the condition of the instrument. This result agrees with those obtained in other experiments with the 4-inch anemometer (page 78), which latter clearly prove that the friction does not vary much if the instrument itself remains unaltered; but from the construction of the larger instruments, and from the nature of the material of which their vanes are formed, they are extremely liable to become disarranged, and altered in form; in fact, it is most difficult to avoid putting them out of form when using them, and it is extremely probable that the alteration in the additive constant is due to this cause.

This view is corroborated by Fig. 162, in which it will be observed that the constant for one of the 4-inch anemometers is altered in consequence of its falling off the wand and becoming deranged, although no alteration in the instrument was observable from the accident. Fig. 163 also elucidates this.

Both the lines deduced from the experiments made with the 12-inch or large anemometers are, it will be seen, curves, and require complicated formulas, while it is somewhat doubtful as to whether the departure from a straight line is due to the circular motion caused by the revolving wand of the Whirling Machine, or is inherent in the nature of the instruments themselves, in which latter case only would it arise on employing the instrument for measuring currents of air in the ordinary way.

157.




Board down on wand, 25-feet circle. V = 9 R + 45·3.

EXPERIMENTS MADE WITH A 6-INCH BIRAM'S ANEMOMETER TO ASCERTAIN THE EFFECT OF REVOLVING IN CIRCLES OF DIFFERENT DIAMETERS, WITH A GOVERNOR OR BOARD FIXED DOWNWARD ON THE WAND OF THE WHIRLING MACHINE, FIG. 157.

| No. of Experiment. | LINE C D, 25-FEET CIRCLE. (C D, 154.) | | | | | LINE A B, 10-FEET CIRCLE. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocity calculated by formula V = ·9 R + 45·3. | Error. More. | Error. Less. | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocity calculated by formula V = ·7676 R + 35·3. | Error. More. | Error. Less. |
| 1 | 56 | 99 | .. | .. | .. | 25 | 69 | .. | .. | .. |
| 2 | 65 | 104 | 104 | .. | .. | 26 | 70 | .. | .. | .. |
| 3 | 75 | 106 | .. | .. | .. | 27 | 68 | 66 | .. | 2 |
| 4 | 71 | 108 | .. | .. | .. | 53 | 86 | .. | .. | .. |
| 5 | 72 | 112 | .. | .. | .. | 54 | 88 | .. | .. | .. |
| 6 | 72 | 113 | .. | .. | .. | 67 | 97 | .. | .. | .. |
| 7 | 107 | 142 | 142 | .. | .. | 68 | 95 | .. | .. | .. |
| 8 | 107 | 142 | .. | .. | .. | 75 | 102 | .. | .. | .. |
| 9 | 107 | 142 | .. | .. | .. | 89 | 115 | .. | .. | .. |
| 10 | 108 | 142 | .. | .. | .. | 87 | 112 | 112 | .. | .. |
| 11 | 150 | 180 | .. | .. | .. | 98 | 122 | .. | .. | .. |
| 12 | 152 | 181 | .. | .. | .. | 99 | 120 | .. | .. | .. |
| 13 | 153 | 183 | .. | .. | .. | 103 | 121 | .. | .. | .. |
| 14 | 153 | 183 | .. | .. | .. | 103 | 122 | .. | .. | .. |
| 15 | 195 | 225 | .. | .. | .. | 107 | 129 | .. | .. | .. |
| 16 | 196 | 223 | .. | .. | .. | 113 | 130 | 131 | 1 | .. |
| 17 | 198 | 225 | 224 | .. | 1 | 115 | 132 | .. | .. | .. |
| 18 | 198 | 225 | .. | .. | .. | 128 | 145 | .. | .. | .. |
| 19 | 199 | 225 | .. | .. | .. | 128 | 145 | .. | .. | .. |
| 20 | 223 | 248 | .. | .. | .. | 139 | 152 | .. | .. | .. |
| 21 | 223 | 248 | .. | .. | .. | 141 | 155 | 154 | .. | 1 |
| 22 | 252 | 267 | 268 | 1 | .. | .. | .. | .. | .. | .. |
| 23 | 253 | 273 | .. | .. | .. | .. | .. | .. | .. | .. |
| 24 | 256 | 273 | .. | .. | .. | .. | .. | .. | .. | .. |

*Comparison of Circles.*—Fig. 157 shows the effect of causing an anemometer to revolve in a 10-feet as compared with a 25-feet circle, on the Whirling Machine, with a governor fixed downwards in both cases; the line C D is the same as the line C D in Fig. 154, and is for the 25-feet circle. On

taking the circle at 10 feet, the constant additive for friction remains unaltered, but the instrument itself revolves quicker than in the larger circle for equal velocities, so that the constant multiplier is reduced.

The anemometer was the same 6-inch Biram in each case.

*Comparison of Circles, Fig.* 158, *to corroborate Experiments, Fig.* 157.—This series of experiments, like those of Fig. 157, give a comparison of the effect of causing anemometers to revolve in circles

158.

of different sizes, with a 12-inch in lieu of a 6-inch anemometer, and without governors. Here, again, the instrument revolves quicker, for a given velocity through the air, in a 10-feet than in a 25-feet circle, showing that the result is not accidental, but has a cause, depending for its amount upon the size of the circle; and this fact renders it probable, that if the circles were indefinitely large, or, what is equivalent, if the anemometers were moved in a straight line through a still atmosphere, the numbers indicated by the index of the instrument would be somewhat less than those obtained in a 25-feet circle; the difference, however, would in all probability be small.

EXPERIMENTS, FIG. 158, MADE WITH A 12-INCH BIRAM'S ANEMOMETER, BY THE WHIRLING MACHINE, WITH A 25-FEET AND A 10-FEET CIRCLE, WITHOUT GOVERNOR-BOARDS.

| No. of Experiment. | Line C F D, 10-feet Circle | | | | | Line A B. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocity calculated by formula V = ·75 R + ·00039 R2 + 47·2. | Error. More. | Error. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·69 R + ·000477 R2 + 63·16. | Error. More. | Error. Less. |
| 1 | 31 | 74 | .. | .. | .. | 19 | 79 | ·78 | .. | 1 |
| 2 | 39 | 77 | .. | .. | .. | 46 | 96 | .. | .. | .. |
| 3 | 64 | 100 | .. | .. | .. | 55 | 102 | .. | .. | .. |
| 4 | 69 | 103 | .. | .. | .. | 67 | 108 | .. | .. | .. |
| 5 | 72 | 107 | .. | .. | .. | 93 | 137 | .. | .. | .. |
| 6 | 73 | 109 | .. | .. | .. | 117 | 158 | .. | .. | .. |
| 7 | 83 | 113 | .. | .. | .. | 119 | 158 | .. | .. | .. |
| 8 | 86 | 117 | .. | .. | .. | 151 | 183 | .. | .. | .. |
| 9 | 93 | 116 | .. | .. | .. | 186 | 208 | .. | .. | .. |
| 10 | 97 | 126 | .. | .. | .. | 185 | 208 | .. | .. | .. |
| 11 | 132 | 155 | .. | .. | .. | 215 | 236 | .. | .. | .. |
| 12 | 133 | 154 | .. | .. | .. | 257 | 276 | .. | .. | .. |
| 13 | 151 | 170 | .. | .. | .. | 267 | 283 | .. | .. | .. |
| 14 | 152 | 170 | .. | .. | .. | 268 | 283 | .. | .. | .. |
| 15 | 191 | 210 | .. | .. | .. | 288 | 300 | .. | .. | .. |
| 16 | 192 | 210 | .. | .. | .. | 305 | 317 | 318 | 1 | .. |
| 17 | 234 | 245 | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 18 | 235 | 245 | .. | .. | .. | 313 | 325 | .. | .. | .. |
| 19 | 265 | 275 | .. | .. | .. | 327 | 342 | .. | .. | .. |
| 20 | 270 | 280 | .. | .. | .. | 333 | 350 | .. | .. | .. |
| 21 | 311 | 320 | .. | .. | .. | 345 | 358 | .. | .. | .. |
| 22 | 316 | 325 | .. | .. | .. | 378 | 392 | 392 | .. | .. |
| 23 | 367 | 375 | .. | .. | .. | 382 | 392 | .. | .. | .. |
| 24 | 374 | 380 | .. | .. | .. | .. | .. | .. | .. | .. |

*Comparison of Anemometers.—Lines formed by Experiments made with Combes' Anemometer, Fig.* 159.—In the various experiments that have been made with these instruments on the Continent, it has been found that the excess of the actual wind velocities, over the particular wind velocities which are required to overcome their fractional resistance, is simply proportional to the number of revolutions performed by them in the unit of time; or, what is the same, to the numbers indicated by the pointers, giving rise to an expression of the form of $V = m R + a$, by means of which the velocity of the wind V can be found when we know the number of revolutions, R, of the instrument in the unit of time, $a$ and $m$ being constants for the same instrument, whatever be the velocity V, or revolutions R.

The above expression is the equation to a straight line. The constants $a$ and $m$ can be determined for any instrument by means of two experimental trials of the number of revolutions corresponding to different ascertained wind velocities; thus, if V and R are the velocity and corresponding number of revolutions or indications given by the pointers in the unit of time in one of such trials, and V' and R' the same respectively on the other trial, then $V = m R + a$, and $V' = m R' + a$, from whence $m = \frac{V - V'}{R - R'}$ and $a = \frac{V' R - V R'}{R - R'}$.

The irregularities in the line made by this instrument are, doubtless, caused by errors in observation, and derangement of the pointers, as it is much more difficult to read off than Biram's instrument, under the peculiar circumstances of revolving on a wand in a circle; but these irregularities would probably not exist when using the instrument in the ordinary way for measuring a current of air. The line for the Biram's anemometer is more uniform, because it can be read off with more ease and accuracy in this kind of experiment.

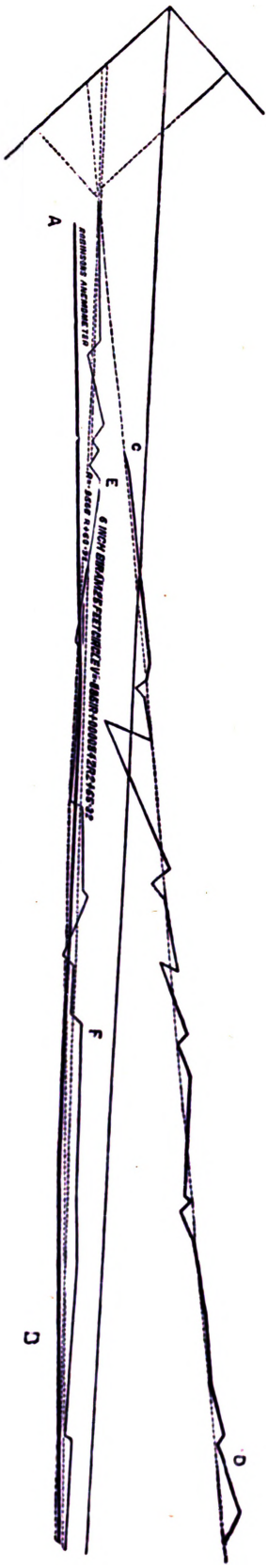
TABLE OF EXPERIMENTS WITH COMBES AND ROBINSON'S ANEMOMETERS, COMPARED WITH BIRAM'S ANEMOMETER, ON WHIRLING MACHINE, 25-FEET CIRCLE, FIG. 159.

| No. of Experiment. | COMBES' LINE, C D. | | | | | ROBINSON'S ANEMOMETER. | | | | | LINE E F. BIRAM'S 6-IN. (same as E E, 160). | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VELOCITY. | | | ERROR. | | VELOCITY. | | | ERROR. | | VELOCITY. | | | | ERROR. | |
| | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocity calculated by formula V = ·738 R + 78. | More. | Less. | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocities calculated by formula V = | More. | Less. | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocities calculated by formula V = ·9568 R + 60·92. | Velocities calculated by formula V = ·8851 R + ·000084·2 R²+65·32 | More. | Less. |
| .. | 201 | 225 | 226 | .. | .. | 67 | 149 | .. | .. | .. | 61 | 125 | .. | .. | .. | .. |
| .. | 213 | 233 | .. | .. | .. | 327 | 368 | .. | .. | .. | 67 | 125 | 124 | 124 | .. | 1 |
| .. | 317 | 308 | .. | .. | .. | 542 | 587 | .. | .. | .. | 140 | 187 | .. | .. | .. | .. |
| .. | 324 | 317 | .. | .. | .. | 777 | 798 | .. | .. | .. | 145 | 200 | .. | .. | .. | .. |
| .. | 325 | 325 | .. | .. | .. | .. | .. | .. | .. | .. | 187 | 225 | .. | .. | .. | .. |
| .. | 332 | 325 | .. | .. | .. | .. | .. | .. | .. | .. | 190 | 237 | .. | .. | .. | .. |
| .. | 336 | 358 | .. | .. | .. | .. | .. | .. | .. | .. | 197 | 237 | .. | .. | .. | .. |
| .. | 433 | 408 | .. | .. | .. | .. | .. | .. | .. | .. | 200 | 250 | .. | .. | .. | .. |
| .. | 359 | 342 | .. | .. | .. | .. | .. | .. | .. | .. | 200 | 250 | .. | .. | .. | .. |
| .. | 369 | 358 | .. | .. | .. | .. | .. | .. | .. | .. | 215 | 250 | .. | .. | .. | .. |
| .. | 433 | 392 | .. | .. | .. | .. | .. | .. | .. | .. | 235 | 275 | .. | .. | .. | .. |
| . | 448 | 408 | .. | .. | .. | .. | .. | .. | .. | .. | 287 | 337 | .. | .. | .. | .. |
| . | 480 | 442 | .. | .. | .. | .. | .. | .. | .. | .. | 292 | 337 | .. | .. | .. | .. |
| .. | 491 | 433 | .. | .. | .. | .. | .. | .. | .. | .. | 367 | 412 | .. | .. | .. | .. |
| .. | 529 | 458 | 460 | 2 | .. | .. | .. | .. | .. | .. | 375 | 412 | .. | .. | .. | .. |
| .. | 529 | 467 | .. | .. | .. | .. | .. | .. | .. | .. | 418 | 450 | .. | .. | .. | .. |
| .. | 552 | 475 | .. | .. | .. | .. | .. | .. | .. | .. | 422 | 450 | .. | .. | .. | .. |
| .. | 613 | 533 | .. | .. | .. | .. | .. | .. | .. | .. | 442 | 487 | .. | .. | .. | .. |
| .. | 616 | 533 | .. | .. | .. | .. | .. | .. | .. | .. | 452 | 487 | .. | .. | .. | .. |
| .. | 618 | 542 | .. | .. | .. | .. | .. | .. | .. | .. | 477 | 512 | .. | .. | .. | .. |
| .. | 618 | 533 | .. | .. | .. | .. | .. | .. | .. | .. | 482 | 512 | .. | .. | .. | .. |
| .. | 641 | 550 | .. | .. | .. | .. | .. | .. | .. | .. | 485 | 512 | .. | .. | .. | .. |
| .. | 690 | 583 | .. | .. | .. | .. | .. | .. | .. | .. | 577 | 600 | .. | .. | .. | .. |
| .. | 722 | 608 | .. | .. | .. | .. | .. | .. | .. | .. | 592 | 612 | .. | .. | .. | .. |
| .. | 752 | 625 | .. | .. | .. | .. | .. | .. | .. | .. | 605 | 625 | .. | .. | .. | .. |
| .. | 756 | 633 | .. | .. | .. | .. | .. | .. | .. | .. | 617 | 637 | .. | .. | .. | .. |
| .. | 740 | 617 | .. | .. | .. | .. | .. | .. | .. | .. | 685 | 712 | .. | .. | .. | .. |
| .. | 797 | 650 | .. | .. | .. | .. | .. | .. | .. | .. | 690 | 712 | .. | .. | .. | .. |
| .. | 811 | 675 | 678 | 3 | .. | .. | .. | .. | .. | .. | 750 | 775 | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 775 | 800 | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 785 | 812 | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 785 | 812 | 811 | 811 | .. | 1 |

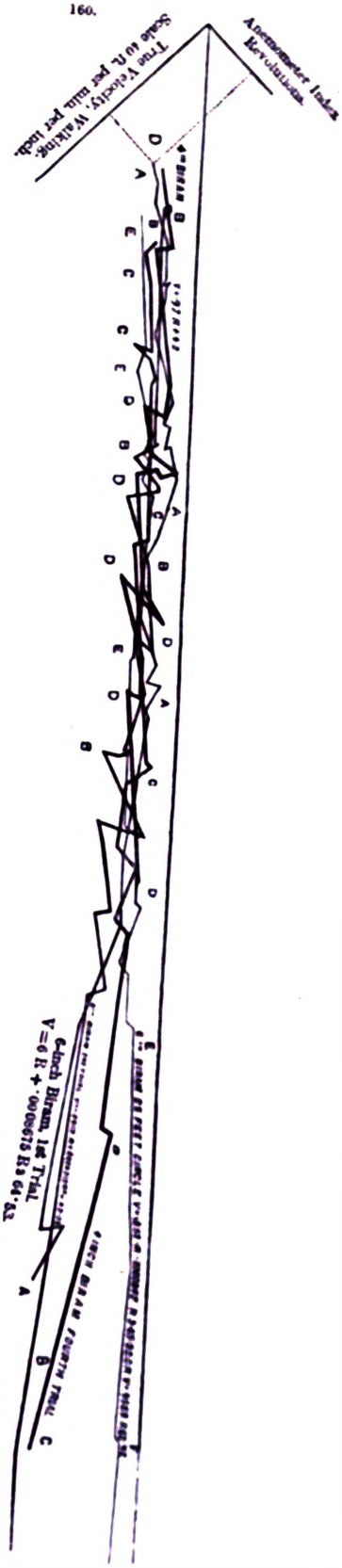
*Moving Anemometers in a Straight Line through a Still Atmosphere, Fig.* 160.—This figure exhibits the results of different sets of experiments made with a 6-inch and 4-inch Biram's anemometer, by a person walking in the still atmosphere of a large granary, and carrying the instrument in his hand; and another set (for the purpose of comparison with those made as above) by the Whirling Machine, in a 25-feet circle, without governors on the revolving-wand. The results obtained in these experiments appear to be both remarkable and important, inasmuch as they indicate that the formulas deduced from the walking experiments do not agree, even within moderate limits, with those obtained by the use of the Whirling Machine; and it becomes a question as to whether the results of either mode are reliable, and if either, as to which mode is so.

All the lines in this diagram are more or less curved. The line E, E, relating to the revolving experiments is, however, less curved than the other lines relating to the experiments made by walking in a straight line, and carrying the instrument through a still atmosphere. The line E, E, indeed, may be regarded as being nearly straight. Of the more recent experiments, the line D, D, may be taken as approaching the straight line: also the line C, C, up to *a*, where it rapidly falls off. This is probably owing to errors at the high velocities.

The line A, A, obtained by walking in a straight line, is much more curved than the line, E, E, of the 25-feet circle,—the multiplier, *m*, of the numbers indicated by the index of the anemometer being much smaller, and the multiplier of the square of the numbers indicated by the index of the



160.


Anemometer Index Revolutions.
True Velocity, Walking. Scale 40 ft. per min. per inch.
6-inch Biram, 1st Trial.
V=6 R + ·0008675 R² 64·52.

EXPERIMENTS, FIG. 160, MADE BY WALKING 500 FEET IN A GRANARY IN A STILL ATMOSPHERE, WITH A 6-INCH AND 4-INCH BIRAM'S ANEMOMETER IN THE HAND, COMPARED WITH EXPERIMENTS MADE WITH THE SAME ANEMOMETER ON THE WHIRLING MACHINE.

| | WALKING. | | | | | | | | | | | | | | | | | | | | MACHINE, 25-FEET CIRCLE. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LINE A A, 1ST TRIAL. | | | | | LINE B B, 2ND TRIAL. | | | | | LINE D D, 3RD TRIAL. | | | | | LINE C C, 4TH TRIAL (taken to "a"). | | | | | LINE E E (same as E E, 160). | | | | | |
| No. of Experiment. | Number indicated by Index of Anemometer = R. | Actual Velocities = V. | Velocity calculated by formula V = ·6 R + ·0008675 R² + 64·53. | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·8512 R + ·0004212 R² + 43·35. | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·97 R + 42. | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = R + 46. | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = ·9568 R + 60·92. | Velocity calculated by formula V = ·8851 R + ·0000842 R² + 65·32. | ERROR. More. | ERROR. Less. |
| 1 | 45 | 96 | .. | .. | .. | 78 | 108 | .. | .. | .. | 51 | 91 | 91 | .. | .. | 90 | 140 | .. | .. | .. | 61 | 125 | .. | .. | .. | .. |
| 2 | 59 | 103 | 103 | .. | .. | 82 | 116 | 115 | .. | 1 | 100 | 125 | .. | .. | .. | 91 | 132 | .. | .. | .. | 67 | 125 | 124 | 124 | .. | 1 |
| 3 | 68 | 111 | .. | .. | .. | 83 | 112 | .. | .. | .. | 93 | 134 | .. | .. | .. | 103 | 149 | 149 | .. | .. | 140 | 187 | .. | .. | .. | .. |
| 4 | 95 | 125 | .. | .. | .. | 93 | 133 | .. | .. | .. | 168 | 190 | .. | .. | .. | 131 | 190 | .. | .. | .. | 145 | 200 | .. | .. | .. | .. |
| 5 | 95 | 125 | .. | .. | .. | 103 | 144 | .. | .. | .. | 184 | 208 | .. | .. | .. | 144 | 186 | .. | .. | .. | 187 | 225 | .. | .. | .. | .. |
| 6 | 97 | 129 | 130 | 1 | .. | 110 | 149 | .. | .. | .. | 171 | 215 | .. | .. | .. | 145 | 190 | .. | .. | .. | 190 | 237 | .. | .. | .. | .. |
| 7 | 98 | 129 | .. | .. | .. | 184 | 219 | .. | .. | .. | 197 | 232 | .. | .. | .. | 157 | 198 | .. | .. | .. | 197 | 237 | .. | .. | .. | .. |
| 8 | 110 | 141 | .. | .. | .. | 187 | 242 | .. | .. | .. | 218 | 232 | .. | .. | .. | 160 | 203 | .. | .. | .. | 200 | 250 | .. | .. | .. | .. |
| 9 | 111 | 144 | .. | .. | .. | 192 | 227 | .. | .. | .. | 212 | 238 | 237 | .. | 1 | 237 | 285 | .. | .. | .. | 200 | 250 | .. | .. | .. | .. |
| 10 | 112 | 139 | .. | .. | .. | 194 | 227 | .. | .. | .. | 207 | 238 | .. | .. | .. | 240 | 276 | .. | .. | .. | 215 | 250 | .. | .. | .. | .. |
| 11 | 116 | 147 | 145 | .. | 2 | 203 | 262 | .. | .. | .. | 197 | 250 | .. | .. | .. | 307 | 338 | .. | .. | .. | 235 | 275 | .. | .. | .. | .. |
| 12 | 121 | 151 | .. | .. | .. | 208 | 242 | .. | .. | .. | 261 | 300 | .. | .. | .. | 355 | 380 | .. | .. | .. | 287 | 337 | .. | .. | .. | .. |
| 13 | 134 | 174 | .. | .. | .. | 208 | 256 | .. | .. | .. | 276 | 303 | .. | .. | .. | 352 | 380 | .. | .. | .. | 292 | 337 | .. | .. | .. | .. |
| 14 | 177 | 197 | .. | .. | .. | 212 | 242 | .. | .. | .. | 245 | 306 | .. | .. | .. | 355 | 399 | 401 | 2 | .. | 367 | 412 | .. | .. | .. | .. |
| 15 | 186 | 211 | .. | .. | .. | 215 | 246 | .. | .. | .. | 287 | 306 | .. | .. | .. | 380 | 434 | .. | .. | .. | 375 | 412 | .. | .. | .. | .. |
| 16 | 191 | 208 | .. | .. | .. | 250 | 285 | 282 | .. | 3 | 259 | 313 | .. | .. | .. | 400 | 434 | .. | .. | .. | 418 | 450 | .. | .. | .. | .. |
| 17 | 194 | 214 | .. | .. | .. | 285 | 326 | .. | .. | .. | 296 | 333 | .. | .. | .. | 418 | 467 | .. | .. | .. | 422 | 450 | .. | .. | .. | .. |
| 18 | 198 | 225 | .. | .. | .. | 289 | 333 | .. | .. | .. | 317 | 353 | .. | .. | .. | 431 | 467 | .. | .. | .. | 442 | 487 | .. | .. | .. | .. |
| 19 | 200 | 222 | .. | .. | .. | 296 | 325 | .. | .. | .. | 307 | 357 | .. | .. | .. | 441 | 480 | .. | .. | .. | 452 | 487 | .. | .. | .. | .. |
| 20 | 220 | 234 | .. | .. | .. | 314 | 349 | .. | .. | .. | 410 | 440 | 441 | .. | .. | 517 | 570 | .. | .. | .. | 477 | 512 | .. | .. | .. | .. |
| 21 | 243 | 270 | .. | .. | .. | 325 | 395 | .. | .. | .. | .. | .. | .. | .. | .. | 525 | 570 | 571 | 1 | .. | 482 | 512 | .. | .. | .. | .. |
| 22 | 243 | 283 | .. | .. | .. | 335 | 389 | .. | .. | .. | .. | .. | .. | .. | .. | 650 | 760 | .. | .. | .. | 485 | 512 | .. | .. | .. | .. |
| 23 | 272 | 312 | .. | .. | .. | 334 | 384 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 577 | 600 | .. | .. | .. | .. |
| 24 | 308 | 329 | .. | .. | .. | 335 | 389 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 592 | 612 | .. | .. | .. | .. |
| 25 | 310 | 344 | .. | .. | .. | 340 | 384 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 605 | 625 | .. | .. | .. | .. |
| 26 | 317 | 337 | .. | .. | .. | 359 | 434 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 617 | 637 | .. | .. | .. | .. |
| 27 | 324 | 353 | .. | .. | .. | 375 | 441 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 685 | 712 | .. | .. | .. | .. |
| 28 | 330 | 357 | .. | .. | .. | 389 | 416 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 690 | 712 | .. | .. | .. | .. |
| 29 | 388 | 435 | .. | .. | .. | 404 | 476 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 750 | 775 | .. | .. | .. | .. |
| 30 | 422 | 468 | .. | .. | .. | 410 | 468 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 775 | 800 | .. | .. | .. | .. |
| 31 | 455 | 595 | .. | .. | .. | 444 | 517 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 785 | 812 | .. | .. | .. | .. |
| 32 | 520 | 625 | .. | .. | .. | 447 | 508 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 785 | 812 | 811 | 811 | .. | 1 |
| 33 | 541 | 652 | .. | .. | .. | 646 | 769 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 34 | 549 | 638 | .. | .. | .. | 687 | 811 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 35 | 549 | 638 | .. | .. | .. | 707 | 769 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |

anemometer being very much larger in the experiments made by walking in a straight line than in the revolving experiments. It appears to be anomalous that the lines relating to experiments in a 10-feet circle should be more curved than those relating to experiments in a 25-feet circle, on the one hand; while the line relating to experiments made in a straight line should, on the other hand, be more curved than either.

Future experiments may possibly throw some light upon this apparent anomaly.

It is stated in Weisbach's 'Mechanics,' that from the experiments of Du Buat and those of Thibault, it would appear that the forces of still air against a flat surface, moved at different velocities through it in a straight line, are proportional to the forces of impact of winds of the same velocities, but less than them in the ratio of 1·4 to 1·85; so that if $V_r$ be the velocity of the wind, and $V_m$ that of the body, in the two cases, then when the velocities are such as to make the resistance in the one case equal to the force of impact in the other, we have $1{\cdot}85\,V_r^2 = 1{\cdot}4\,V_m^2$, and hence $V_r = \sqrt{\frac{1{\cdot}4}{1{\cdot}85}}\,V_m = 0{\cdot}87\,V_m$, from which we see that the velocity of wind only appears to require to be 0·87 of that of a body moved through still air in a straight line, to give rise to the same force against the body; and hence it may be that the velocities calculated from our formulas, deduced from the walking or Whirling Machine experiments, would require, when the anemometer is employed in the ordinary way for measuring a current of air, to be multiplied by 0·87, to give the true velocity of the wind; but on this point Atkinson and Daglish entertain very grave doubts, as such results do not appear, *a priori*, to be probable, and the subject is one in which mistakes are very liable to occur.

In like manner, when a flat surface is moved against a still atmosphere in a circle, the experiments of Hutton, Borda, and Thibault appear to indicate that at a given velocity the force or resistance is only about 1·5, compared with a force of 1·85 for the same velocity when the flat surface is at rest, and the air moves, as a wind, against it; so that if $V_o$ be the velocity of a flat surface moving in a circle, and $V_r$ the velocity of a wind giving rise to the same force, then, in order that the force in the one case may be equal to the resistance in the other, we have the velocities such that $1{\cdot}85\,V^2 = 1{\cdot}5\,V_o^2$, from whence $V_r = \sqrt{\frac{1{\cdot}5}{1{\cdot}85}}\,V_o = {\cdot}9\,V_o$, from which it would appear that the velocities of wind, as deduced from the formulas found by the experiments made with the Whirling Machine, should be reduced by multiplying them by ·9 in order to get the actual velocities of the wind. There is, however, said to be more grave doubts still as to the correctness of this conclusion, and for the present it is preferred to leave it out of the formulas given.

The discrepancy between the line E, E, in Fig. 160, representing $V_o$, and the lines B, B, A, A, representing $V_m$, are much greater than the differences just alluded to would appear to indicate, and hence there is reason to suppose that the data are not reliable; indeed, it may be seen that Weisbach, in adopting 1·85, 1·4, and 1·5 as multipliers of the motive column to give the force or resistance due to a wind, to moving a flat surface in a straight line through still air, and then in a circle, respectively, makes no distinction between a large and a small circle; while a glance at Fig. 158 appears to show that the size of the circle has considerable influence upon the amount of the resistance the body meets with in its revolutions through still air at any velocity.

It should, however, also be stated that the discrepancies between the line E, E, on the one hand, and the lines B, B, A, A, and other lines on the other hand, in Fig. 160, chiefly prevail at the higher velocities, and probably arise from the errors of observation, owing to the experimenter having to run at considerable speeds; the jolting motion arising from this, and the disturbance of the air by his body, must be considerable. The formula for the lines D, D, C, C, is obtained only up to a velocity of 500 feet per minute, up to which point the diagram exhibits a straight line, conforming very closely with that given by the Whirling Machine.

The height of a column of a fluid, $h$, in feet, required to generate a velocity of $V_1$ in feet per second, apart from friction, is expressed by $h_1 = \frac{V_1^2}{2g}$, when $g = 32\frac{1}{6}$, giving $h_1 = \frac{V_1^2}{64\frac{1}{3}}$; or, where $h_2$ is the height of the column due to $V_2$, the velocity in feet per minute, this becomes $h_2 = \frac{V_2^2}{231{,}000}$, and from the experiments of the authors just mentioned, it would appear that the impact of a fluid in motion would support a vertical column of the height $f_r$ in feet, expressed by $f_r = \frac{1{\cdot}85\,V_2^2}{231{,}000} = \frac{1{\cdot}85\,V_1^2}{64\frac{1}{3}}$; or $f_r = \frac{V_2^2}{125{,}189} = \frac{V_1^2}{34{\cdot}77}$. (See Acceleration.) While if the fluid is at rest, and the body (having in each case a flat surface) is moved in a straight line, the resistance $f_m$ in height in feet of a column of the fluid would only amount to $f_m = \frac{1{\cdot}4\,V_2^2}{231{,}000} = \frac{1{\cdot}4\,V_1^2}{64\frac{1}{3}}$ or $f_m = \frac{V_2^2}{165{,}429} = \frac{V_1^2}{45{\cdot}952}$, or if the body were moved in a circle, the resistance would support a column of the fluid $f_o$ feet in height found by $f_o = \frac{1{\cdot}5\,V_2^2}{231{,}000} = \frac{1{\cdot}5\,V_1^2}{64\frac{1}{3}}$ or $f_o = \frac{V_2^2}{154{,}000} = \frac{V_1^2}{42{\cdot}889}$.

The experiments shown in Fig. 161 were made for the purpose of observing whether the action of Biram's anemometer varied much with the condition of the instrument, that is, whether the same formula and constants were required for the same instrument when properly cleaned and oiled, and again, after being much used and in a dirty condition; and it is certainly satisfactory to find, as will be observed in Fig. 161, that the action of the same instrument is very little altered through these varied conditions.

The line A, A, on this diagram shows the velocity found by correcting the readings of the

anemometer by the formula (for this particular instrument), V = 1·017 R + 30; and it will be remarked how very close the line approximates to the true velocity of the instrument passing through the air, as found by the Whirling Machine.

EXPERIMENTS, FIG. 161, MADE WITH A 6-INCH BIRAM'S ANEMOMETER, IN CLEAN AND DIRTY CONDITIONS RESPECTIVELY, ON THE WHIRLING MACHINE, IN A 25-FEET CIRCLE.

| No. of Experiment. | LINE B B.—INSTRUMENT CLEAN. | | | | | LINE C C.—INSTRUMENT DIRTY. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = 1·017 R + 30. | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = R + 30. | ERROR. More. | ERROR. Less. |
| 1 | 93 | 125 | 125 | .. | .. | 62 | 100 | .. | .. | .. |
| 2 | 120 | 150 | 152 | 2 | .. | 80 | 119 | .. | .. | .. |
| 3 | 133 | 162 | 165 | 3 | .. | 100 | 137 | .. | .. | .. |
| 4 | 412 | 450 | 449 | .. | 1 | 365 | 400 | .. | .. | .. |
| 5 | 412 | 450 | 449 | .. | 1 | 395 | 427 | .. | .. | .. |
| 6 | 422 | 450 | 459 | 9 | .. | 425 | 462 | .. | .. | .. |
| 7 | 427 | 462 | 464 | 2 | .. | 585 | 625 | .. | .. | .. |
| 8 | 582 | 625 | 622 | .. | 3 | 585 | 625 | .. | .. | .. |
| 9 | 585 | 625 | 625 | .. | .. | .. | .. | .. | .. | .. |
| 10 | 592 | 637 | 632 | .. | 5 | .. | .. | .. | .. | .. |

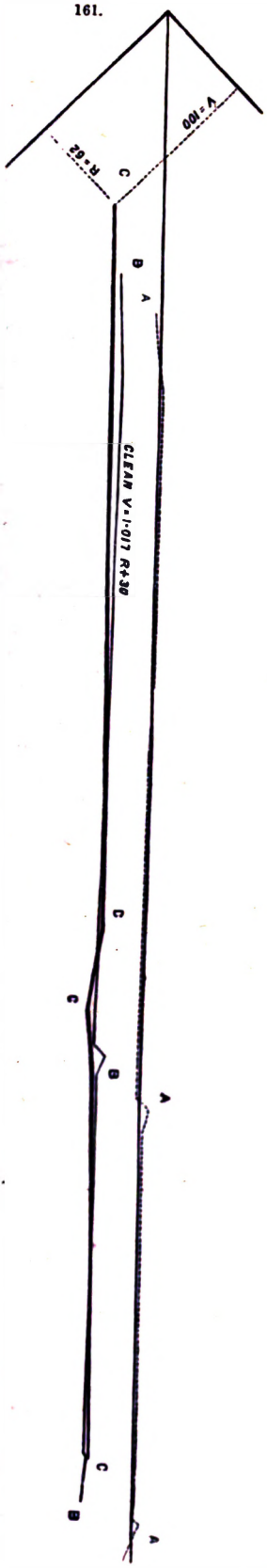
EXPERIMENTS, FIG. 162, MADE WITH SEVERAL ANEMOMETERS (BIRAM'S) ON WHIRLING MACHINE, IN 25-FEET CIRCLE, TO FIND CONSTANTS *m* AND *a*.

| No. of Experiment. | LINE E E F.—4-IN. BIRAM. | | | | | LINE C D.—4-IN. BIRAM. | | | | | LINE J I.—4-IN. BIRAM. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = | ERROR. More. | ERROR. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V = | ERROR. More. | ERROR. Less |
| 1 | 205 | 250 | .. | .. | .. | 187 | 237 | .. | .. | .. | 77 | 131 | .. | .. | .. |
| 2 | 210 | 262 | .. | .. | .. | 200 | 250 | .. | .. | .. | 82 | 137 | .. | .. | .. |
| 3 | 215 | 262 | .. | .. | .. | 255 | 300 | .. | .. | .. | 182 | 225 | .. | .. | .. |
| 4 | 340 | 387 | .. | .. | .. | 337 | 387 | .. | .. | .. | 200 | 237 | .. | .. | .. |
| 5 | 345 | 387 | .. | .. | .. | 340 | 387 | .. | .. | .. | 230 | 262 | .. | .. | .. |
| 6 | 360 | 400 | .. | .. | .. | 350 | 400 | .. | .. | .. | 242 | 275 | .. | .. | .. |
| 7 | 405 | 462 | .. | .. | .. | 477 | 537 | .. | .. | .. | 312 | 350 | .. | .. | .. |
| 8 | 412 | 475 | .. | .. | .. | 480 | 537 | .. | .. | .. | 320 | 362 | .. | .. | .. |
| 9 | 437 | 500 | .. | .. | .. | 490 | 550 | .. | .. | .. | 375 | 412 | .. | .. | .. |
| 10 | 440 | 500 | .. | .. | .. | .. | .. | .. | .. | .. | 460 | 500 | .. | .. | .. |
| 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 487 | 525 | .. | .. | .. |
| 12 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 510 | 550 | .. | .. | .. |

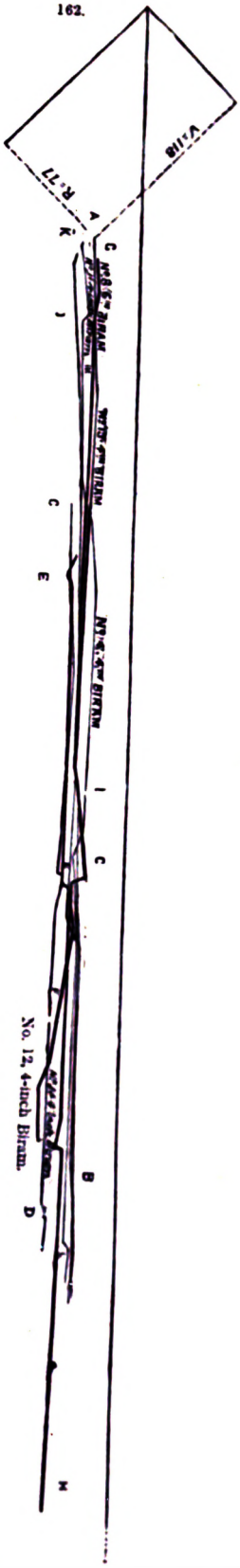
| | LINE D D D, 160.—4-IN. BIRAM. | | | | | LINE K K L, 162.—4-IN. BIRAM. | | | | | LINE A B, 159.—6-IN. BIRAM. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 77 | 118 | .. | .. | .. | 76 | 125 | .. | .. | .. | 87 | 125 | .. | .. | .. |
| 2 | 112 | 150 | .. | .. | .. | 107 | 150 | .. | .. | .. | 102 | 137 | .. | .. | .. |
| 3 | 152 | 187 | .. | .. | .. | 110 | 156 | .. | .. | .. | 112 | 150 | .. | .. | .. |
| 4 | 342 | 387 | .. | .. | .. | 335 | 375 | .. | .. | .. | 295 | 337 | .. | .. | .. |
| 5 | 357 | 400 | .. | .. | .. | 372 | 412 | .. | .. | .. | 337 | 375 | .. | .. | .. |
| 6 | 377 | 412 | .. | .. | .. | 385 | 425 | .. | .. | .. | 342 | 385 | .. | .. | .. |
| 7 | 377 | 412 | .. | .. | .. | .. | .. | .. | .. | .. | 440 | 487 | .. | .. | .. |
| 8 | 460 | 500 | .. | .. | .. | 492 | 537 | .. | .. | .. | 450 | 500 | .. | .. | .. |
| 9 | 500 | 537 | .. | .. | .. | 497 | 537 | .. | .. | .. | 452 | 500 | .. | .. | .. |
| 10 | 520 | 562 | .. | .. | .. | 507 | 550 | .. | .. | .. | 557 | 612 | .. | .. | .. |
| 11 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 640 | 700 | .. | .. | .. |

Fig. 162 exhibits a series of lines formed by various 4 and 6 inch Biram's anemometers, with which experiments have been tried. It will be observed that, although the general tendency of the lines formed by the different anemometers is in the same direction, thus giving one general form of formula applicable to all of them; still each anemometer has a decided line of its own, requiring that special constants, found by direct experiment, should be applied to each instrument.

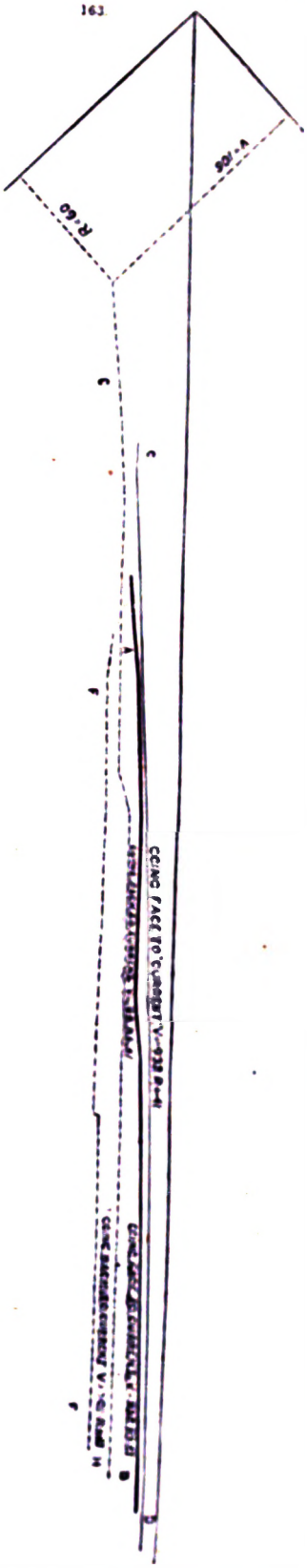
161.




162.




163.



In making one of the experiments, the anemometer fell off the wand of the Whirling Machine (the line E F), and although it sustained no apparent damage, still the line made by this instrument was altered at and from this point. The instrument was apparently not damaged, but the constants required for the correction of its readings were altered, owing possibly to some alteration in the form of the vanes; showing that although, as previously explained, Fig. 161, the fact of the instrument being in a clean or dirty condition does not seriously affect its readings, still any sudden shock, or other violent treatment tending to vary the form of the vanes, or otherwise alter the mechanical condition of the instrument, would do so.

But even in this case the discrepancy caused by the fall seems to be much less in amount than the inaccuracy of the original readings; and the application of the formula, as first found, would still render the readings much more correct than if they were used in their uncorrected state.

Atkinson and Daglish made experiments for the purpose of observing the comparative rates of revolution of the same Biram's anemometer, when passed through a still atmosphere, by the Whirling Machine, in the first instance with its back, and again with its face towards the direction of its motion; the former being the ordinary mode of operating.

As there were considerable differences in the results given by these experiments, evidently depending upon whether the front or the back of the instrument received the impulse of the air, so that when plotted to form a diagram the lines appeared considerably apart from each other, showing that the same formula could not apply to the instrument under the variation of conditions involved in the experiments, another series of similar experiments was made, further to test the truth of the conclusion indicated by the former series. The results of these experiments only served to confirm the former ones.

The two lines F, F, A B, Fig. 163, are formed from experiments registered in the following Table; and the two lines G H, C D, from these experiments; the line G H, in each case being that given when the back of the anemometer received the impulse of the current, as is correct in practice.

EXPERIMENTS, FIG. 163, MADE WITH A 4-INCH BIRAM'S ANEMOMETER ON THE WHIRLING MACHINE, IN A 25-FEET CIRCLE, TO ASCERTAIN THE DIFFERENCE BETWEEN THE ANEMOMETER GOING THE BACK TO CURRENT AND FACE TO CURRENT.

| No. of Experiment. | LINE F F.—ANEMOMETER GOING BACK TO CURRENT. | | | | | LINE A B.—ANEMOMETER GOING FACE TO CURRENT. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V= 1·01 R+41. | Error. More. | Error. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V= ·932 R+41. | Error. More. | Error. Less. |
| 1 | 172 | 212 | 214 | .. | .. | 157 | 187 | 187 | .. | .. |
| 2 | 182 | 225 | .. | .. | .. | 192 | 218 | .. | .. | .. |
| 3 | 315 | 362 | .. | .. | .. | 240 | 262 | .. | .. | .. |
| 4 | 317 | 362 | 361 | .. | 1 | 290 | 312 | .. | .. | .. |
| 5 | 405 | 450 | .. | .. | .. | 307 | 325 | 326 | 1 | .. |
| 6 | 417 | 462 | 462 | .. | .. | 332 | 350 | .. | .. | .. |
| | .. | .. | .. | .. | .. | 425 | 437 | .. | .. | .. |
| | .. | .. | .. | .. | .. | 450 | 462 | .. | .. | .. |
| | .. | .. | .. | .. | .. | 450 | 462 | 460 | .. | 2 |

| No. of Experiment. | LINE G H.—ANEMOMETER GOING BACK TO CURRENT. | | | | | LINE C D.—ANEMOMETER GOING FACE TO CURRENT. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V= ·98 R + 41. | Error. More. | Error. Less. | Number indicated by Index of Anemometer = R. | Actual Velocity = V. | Velocity calculated by formula V= ·932 R + 41. | Error. More. | Error. Less. |
| 1 | 60 | 106 | .. | .. | .. | 112 | 144 | 145 | 1 | .. |
| 2 | 65 | 109 | .. | .. | .. | 117 | 150 | .. | .. | .. |
| 3 | 122 | 162 | 161 | .. | .. | 256 | 275 | .. | .. | .. |
| 4 | 135 | 172 | .. | .. | .. | 297 | 312 | .. | .. | .. |
| 5 | 213 | 250 | .. | .. | .. | 390 | 400 | .. | .. | .. |
| 6 | 230 | 262 | .. | .. | .. | 440 | 450 | .. | .. | .. |
| 7 | 317 | 350 | .. | .. | .. | 467 | 475 | 475 | .. | .. |
| 8 | 367 | 400 | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | 442 | 475 | 474 | .. | .. | .. | .. | .. | .. | .. |

These results prove that the *additive* constant remains the same in the same instrument when used either side foremost, but that, on the other hand, the amount of the necessary *multiplicative* constant depends upon the form of the wands receiving the impulse of the wind, as had been anticipated and mentioned in the remarks upon Figs. 161, 162.

In general principles the anemometers of Whewell and Osler are similar to those of Combes and Biram, but by additional apparatus the two former are made self-registering, both in reference to the force and direction of the wind; this, of course, adds to the friction of the instrument, and they are not, therefore, adapted for ascertaining the velocities of feeble currents.

The anemometer of Dr. Robinson is constructed on the assumption that the force of impact of the air against hollow hemispherical cups is twice as great on the concave as on the convex side of the cups, and that the vanes revolve at the rate of one-third of the velocity of the current, except in so far as the velocity of revolution is modified by friction.

The mechanism of this instrument is very strong, and allows of the revolutions being recorded throughout a whole day; it would, therefore, be a very suitable anemometer to have near a furnace, or in the principal intake or return from a mine.

*Pressure Anemometers.*—Perhaps amongst the best known of the pressure anemometers are M. Bongui's, Dr. Lind's, that of Henaut, described by Ponson, and Dickinson's, one of Her Majesty's Inspectors of Mines. The anemometer of Bongui consists of an apparatus like a spring-balance, furnished with a float-board or plain surface of given area, and the pressure or impulse is indicated by marks on the sliding-rod of the spring; it is figured and described in the 'Edinburgh Encyclopædia.'

The anemometer of Dr. Lind resembles the photometer of Pitôt; it determines the velocity of the wind by its action on a small quantity of water in a U-shaped tube. As the same instrument is much used in coal mines as a water-gauge for indicating the difference of pressure between the downcast and upcast air-column, it will not be at all necessary to give a detailed description of it. From numerous experiments, Dr. Lind considered that the pressure of the wind in direct impulse is nearly proportional to the square of its *velocity*. The following Table is calculated from this, but considerably enlarged by other experiments.

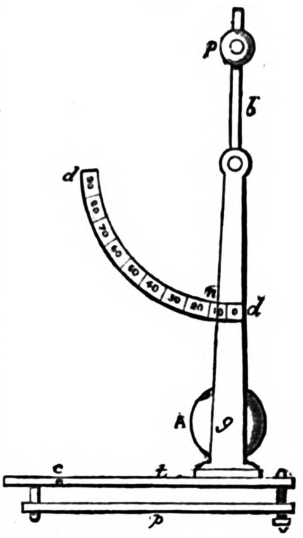
TABLE OF THE FORCE AND VELOCITY OF DIFFERENT WINDS FOR THE GRADUATION OF ANEMOMETERS. ('Edinburgh Encyclopædia.')

| Height of the column of water in Dr. Lind's Anemometer. | Force on a sq. foot, in pounds avoirdupois. | Force on a sq. foot, in pounds, ounces, and drams avoirdupois. | Feet in one second. | Miles in one hour. | Feet in one second. | Miles in one hour. | Character of the Winds. |
|---|---|---|---|---|---|---|---|
| | | | Computed from Rouse's Experiments. | | Computed from Dr. Hutton's Experiments. | | |
| | | lbs. oz. dr. | | | | | |
| 0·0009515 | 0·005 | 0 0 1·280 | 1·43 | 1 | 1·63 | 1·11 | Hardly perceptible .. .. Rouse. |
| 0·0038060 | 0·020 | 0 0 5·120 | 2·93 | 2 | 3·26 | 2·22 | Just perceptible .. .. Rouse. |
| 0·0083732 | 0·044 | 0 0 11·264 | 4·40 | 3 | 4·84 | 3 30 | |
| 0·0133210 | 0·079 | 0 1 4·224 | 5·87 | 4 | 6·52 | 4·44 | Gentle winds .. . .. Rouse. |
| 0·023 | 0·123 | 0 1 15·488 | 7·33 | 5 | 8·09 | 5·51 | |
| 0·025 | 0·130 | 0 2 1·280 | 7·55 | 5·14 | 8·33 | 5·67 | A gentle wind .. . .. Lind. |
| 0·050 | 0·260 | 0 4 2·560 | 10·67 | 7·27 | 11·77 | 8·00 | Pleasant wind .. .. .. Lind. |
| 0·092 | 0·492 | 0 7 13·952 | 14·67 | 10·00 | 16·16 | 11·01 | Pleasant brisk gale.. .. Rouse. |
| 0·10 | 0·521 | 0 8 5·378 | 15·19 | 10·35 | 16·66 | 11·35 | Fresh breeze .. .. .. Lind. |
| 0·11 | 1·107 | 1 1 11·392 | 22·00 | 15·00 | 24·30 | 16·57 | Brisk gale .. .. .. .. Rouse. |
| 0·368 | 1·968 | 1 15 7·808 | 29·34 | 20·00 | 32·39 | 22·00 | Very brisk .. .. .. Rouse. |
| 0·5 | 2·604 | 2 9 10·624 | 33·74 | 23·00 | 37·26 | 25·40 | Brisk gale . .. .. .. Lind. |
| 0·585 | 3·075 | 3 1 3·200 | 36·67 | 25· | 40·51 | 27·62 | Very brisk .. .. .. Rouse. |
| 0·84 | 4·429 | 4 6 13·824 | 44·01 | 30· | 48·60 | 33·13 | High wind .. .. .. Rouse. |
| 1·0 | 5·208 | 5 3 5·248 | 47·73 | 32·54 | 52·70 | 35·93 | High wind .. .. .. Lind. |
| 1·146 | 6·027 | 6 0 6 912 | 51·34 | 35· | 56·69 | 38·65 | |
| 1·5 | 7·873 | 7 13 10·688 | 58·68 | 40· | 64·79 | 44·00 | Very high .. .. . .. Rouse. |
| 1·9 | 9·963 | 9 15 6·528 | 66·01 | 45· | 72·89 | 49·69 | Great storm .. . .. Denham |
| 2·0 | 10·417 | 10 6 10·496 | 67·50 | 46·02 | 74·53 | 50·81 | Very high .. .. .. .. Lind. |
| 2·68 | 12 300 | 12 4 12 800 | 73 35 | 50· | 81 02 | 55·24 | Storm or tempest .. .. Rouse. |
| 3· | 15·625 | 15 10 00·000 | 82 67 | 56·37 | 91·28 | 62·23 | Storm .. .. .. .. Lind. |
| 3·37 | 17·715 | 17 11 7·040 | 88·02 | 60· | 97·20 | 66·27 | Great storm .. .. .. Rouse. |
| 4· | 20·833 | 20 13 5·248 | 95·46 | 65·08 | 105·40 | 71·86 | Great storm .. .. .. Lind. |
| 4 08 | 21·435 | 21 6 15 360 | 96·82 | 66· | 106·92 | 74·79 | Great storm .. La Condamina. |
| 5· | 26·041 | 26 0 10 496 | 106 72 | 72·76 | 117·84 | 80·10 | Very great storm .. .. Lind. |
| 6· | 31·490 | 31 7 13 440 | 117·36 | 80· | 129·59 | 88·54 | Hurricane .. .. .. Rouse. |
| 6· | 31·250 | 31 4 00 000 | 116·91 | 79·71 | 129·09 | 88·01 | Hurricane .. .. .. Lind. |
| 7· | 36·548 | 36 8 12·288 | 126 43 | 86·20 | 139·65 | 95·21 | Great hurricane .. .. Lind. |
| 8· | 41·667 | 41 10 10·752 | 135·00 | 92·04 | 149·07 | 101·63 | Very great hurricane .. Lind. |
| 9· | 46·875 | 46 14 00·000 | 143·11 | 97·57 | 168·11 | 107 80 | Most violent hurricane .. Lind. |
| 9·36 | 49·200 | 49 3 3·200 | 146 70 | 100· | 162·04 | 110·48 | Hurricane that tears up trees and throws down buildings .. .. .. Rouse. |
| 10· | 52·083 | 52 1 5·248 | 150·93 | 102·90 | 166·66 | 113·63 | |
| 11· | 57·293 | 57 4 11·008 | 158 29 | 107·92 | 171·72 | 117·08 | |
| 11·12 | 58·450 | 58 7 3·200 | 160 00 | 109· | 176·55 | 120·37 | Observed by Rochon. |
| 12· | 62·500 | 62 8 0·000 | 165·34 | 112·73 | 182·57 | 124·47 | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

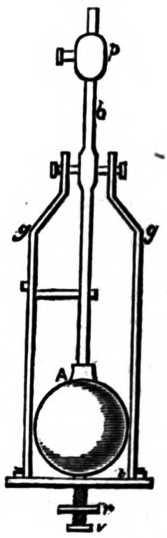
Borda, however, found that the force of the wind was greater by $\frac{1}{10}$ part than Rouse's Table gives. Hutton also showed that the forces at very great velocities increased in a somewhat higher ratio than the squares of the velocity.

**Henaut's anemometer**, Figs. 164, 165, is similar in its principle and action to that of Dickinson; in the latter the impulse is received on a plain surface A, of oiled skin about 3 inches square, suspended from the top *p*, the variations of which, from the perpendicular *p b d q*, are noted on a scale *d d s*, which is marked off by direct experiments. This instrument is extremely portable, and not easily put out of order; but whilst it possesses the great value, with other instruments of this class, of not requiring any watch or other means of noting the time, it is, in common with them, subject to the great disadvantage of vibrating continually, especially in a rapid current, and of not recording the variation of the velocity within limits of 20 feet per minute; it is, however, very useful in steady currents of from 200 to 700 feet per minute. The supports *g g*, are secured to a base *c t*, which is levelled by screws *r v*.

164.




165.




*Complex Anemometers.*—The principle of the interesting method proposed by Professor Leslie for finding the velocity of an air-current by its cooling action, can be studied at length in his 'Treatise on Heat.' From his experiments he deduced the following:—"A thermometer is held in the open, still atmosphere, and the temperature marked; it is then warmed by the application of the hand, and the time noted which it takes to sink back to the normal point; this is termed the fundamental measure of cooling. The same observation is made on exposing the bulb to the impression of the wind, and the time required for the bisection of the interval of temperatures is termed the occasional measure of cooling; then divide the fundamental by the occasional measure of cooling, and the increase of the quotient above unity, being multiplied by 4½, will express the velocity of the wind in miles per hour."

ANGLE-BEAD. Fr., *Corniche de cornière, Chapelet angulaire;* Ger., *Winkel oder Eck Karniess;* Span., *Guarda-vivo.*

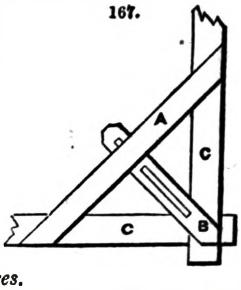
Angle-bead, sometimes termed *Staff-bead*, shown in Fig. 166, is a small round moulding, often cut into short embossments, like pearls in a necklace. In plastering, angle-beads are made flush with the finished surface on each return to assist in floating the plaster; they are nailed to plugs or to wood-bricks built into the wall. Angle-beads are in some cases made to show double on each face of a corner, thus forming a triple bead; however, in superior apartments a triple bead is not employed, but the plaster is well gauged and brought to an *arris*, a thin copper angle-bar being in most cases fitted in to preserve the corner from accidental fracture. Wooden angle-beads are fixed to the jambs of arched recesses, the bead round the head of the arch is formed with plaster, and in good work it is necessary to conceal the joint between the plaster and wooden beads by an *impost*.

166.

ANGLE-BRACE. Fr., *Attache angulaire;* Ger., *Winkel Strebe;* Ital., *Calastrello d'angolo, Traversa;* Span., *Tirante.*

Any framing when situated on the inner side of an angle, for the purpose of tying the work together, is termed an angle-brace. In Fig. 167, representing the framing of the external angle of a building, A is the angle-brace, B dragon-piece, and C C wall-plates.

167.




The term angle-brace is also applied to a tool for boring in corners and other confined localities where there is not space to use the cranked handle of a common brace. It is composed of metal, and works by means of two bevel-pinions, and a winch-handle which turns at right angles to the centre of the hole to be pierced. See Brace.

Angle-Bracket.

ANGLE-BRACKETS. Fr., *Tasseaux angulaires, Support angulaire;* Ger., *Winkellager;* Ital., *Gattello, Measola d'angolo;* Span., *Modillones angulares.*

A bracket projecting from the angle of a wall or building, instead of at right angles, as from the face of a wall, is termed an angle-bracket.

Let D B A, Fig. 168, be the elevation of the bracket of a cove, to find the angle-bracket.

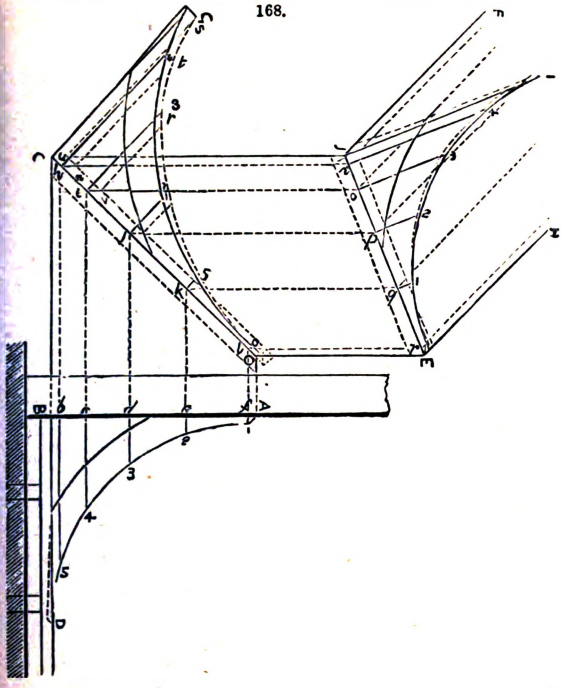
First, when it is a mitre-bracket in an interior angle, the angle being 45°, divide the curve A D into any number of equal parts 5 4 3 2 1, and draw through the divisions of the lines 5 *b*, 4 *c*, 3 *d*, 2 *e*, 1 *f*, perpendicular to B A, and cutting it in *b c d e f*, and produce them to meet the line C O, representing the centre of the seat of the angle-bracket; and from the points of intersection *w i j k l* draw lines *w* 4, *i* 3, *j* 1, *k* 5, at right angles to C O, and make them equal—*w* 4 to *b* 5, *i* 3 to *c* 4, *j* 1 to *d* 3, and so on; and through G 4 3 1 5 0 draw the curve of the edge of the bracket. The dotted lines on each side of C O on the plan show the thickness of the bracket, and the dotted lines *u s*, *n t*, *v r*, show the manner of finding the bevel of the base.

The same figure shows the manner of finding the bracket for an obtuse exterior angle. Let C J F be the exterior angle, bisect it by the line J E, which will represent the seat of the centre of the bracket. The lines J I, *s* 4, *o* 3, *p* 2, *q* 1, *r*, are drawn perpendicular to J E, and their lengths are found as in the former case.

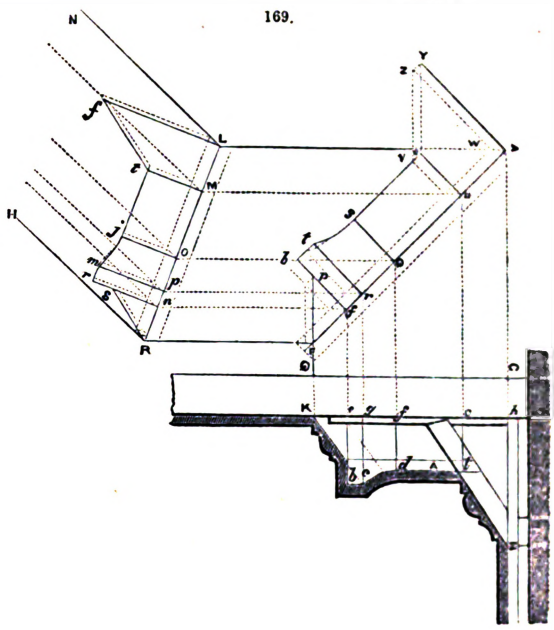
To find the angle-bracket of a cornice for interior and exterior angles. Let K A B, Fig. 169, be

the elevation of the cornice-bracket, F A the seat of the mitre-bracket of the interior angle, and L R that of the mitre-bracket of the exterior angle. From the points K *b c d t* B, or wherever a change

168.

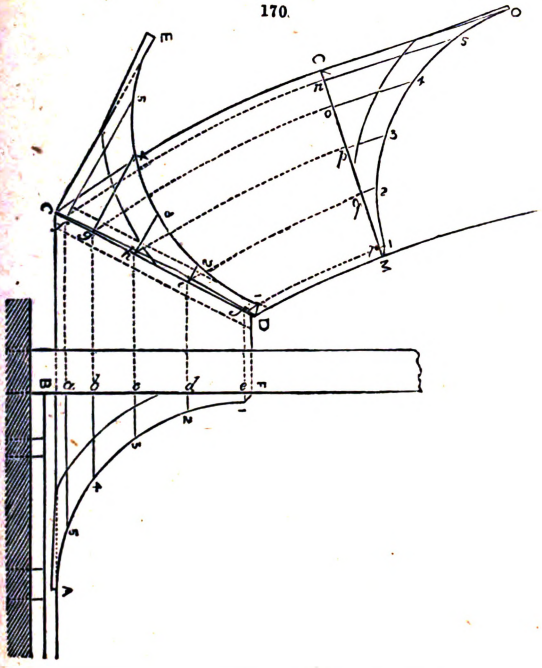


169.

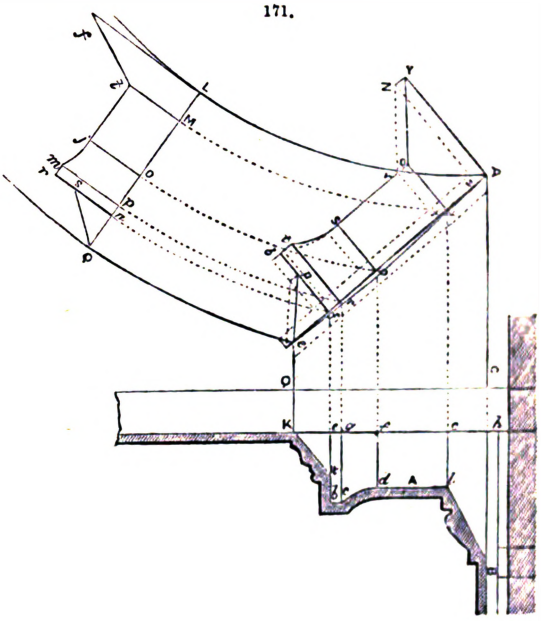


in the form of the contour of the bracket occurs, draw lines perpendicular to K *h* or Q C, cutting K *h* in *e g f c h*, and cutting the line F A in F *f r* Q *u* A. Draw the lines F R, R H, and A L, L N, representing the plan of the bracketing, and the parallel lines from the intersections *n p o* M, as shown dotted in the engraving, then make A Y and L *f* each equal to *h* B, *u o* and M *t* to *c t*, Q S and *o j* equal to *f d*, *r t* and *p m* equal to *g c*, *f b* and *n r* equal to *e b*, *f p* and *n s* equal to *e b*, and join the points so found to give the contour of the brackets required. The bevels of the face are found as shown by the dotted lines W Z V *b*.

170.



171.



To find the angle-bracket at the meeting of a concave curved wall with a straight wall

Let B C D F, Fig. 170, be the plan of the bracketing on the straight wall, and C C, M D the plan on the circular wall, A B F the elevation on the straight wall and M C O on the circular wall.

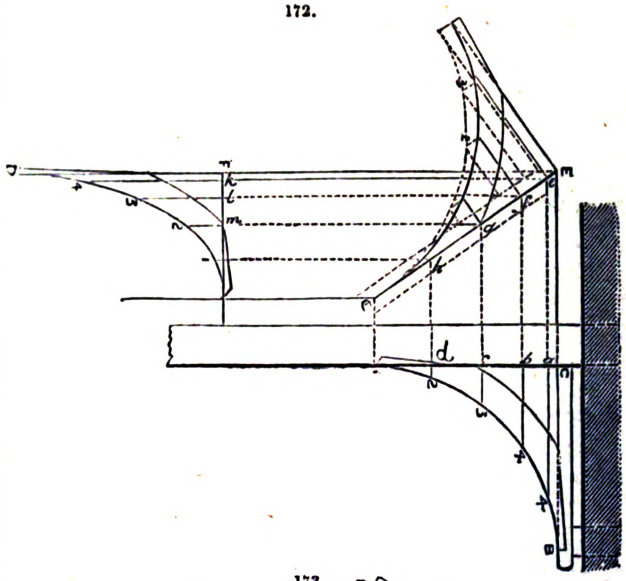
Divide the curves A F, M O into the same number of equal parts; through the divisions of A F draw the lines A C, 5 *a f*, 4 *b g*, and so on, perpendicular to B F, and through those of M O draw the parallel lines, part straight and part curved, 5 *n f*, 4 *o g*, 3 *p h*, and so on. Then through the intersections *f g h i* of the straight and curved lines draw the curve C D, which will give the line from which to measure the ordinates *f* 5, *g* 4, *h* 3, *i* 2, *j* 1.

To find the angle-bracket when the wall is a convex curve.

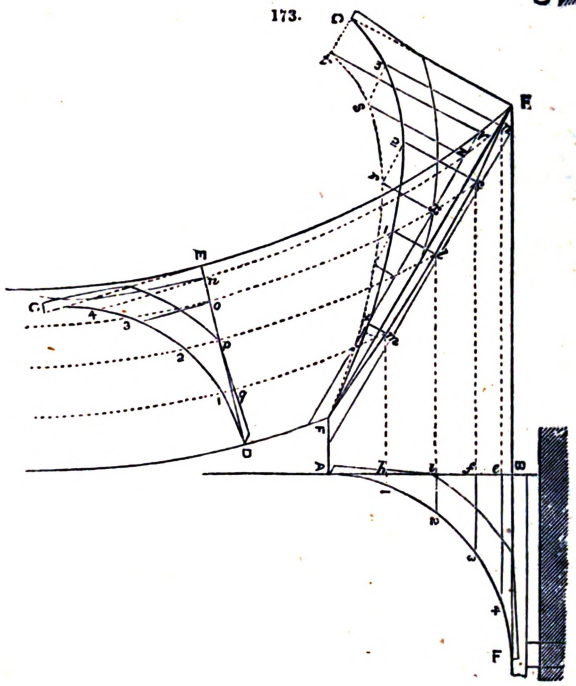
Let A *e* Q C, Fig. 171, be the plan of the bracketing on the straight wall, and A *e* Q L the plan on the curved wall. From the points K *t b c d* b B of the bracket K A B, where its contour changes, draw perpendiculars as before. Draw L Q a radius to the curve of the wall L A, and set on it the divisions M *o p n*, equal and corresponding to *c f g e* of the elevation K A B; and draw L *f*, M *t*, *o j*, *p m*, *n r*, *n s*, perpendicular to Q L, and make them equal to *h* B, *c l*, *f d*, *g c*, *e b*, *e t*, of the elevation; then join the points by the lines *f t*, *t j*, *j m*, *m r*, *r s*, *s* Q, to obtain the contour of the bracket equal and corresponding K A B. Through the points M *o p n* draw concentric curves, meeting the perpendiculars from the corresponding points of K A B; from the intersections of the straight and curved lines, *u o r f*, draw the lines A Y, *u o*, *o s*, *r t*, *f b*, perpendicular to *e* A, and make them equal to the corresponding lines of the elevation, as before; then join the points Y *o s t b p e* to obtain the contour of the angle-bracket.

The examples shown in Figs. 172, 173, are projected in a similar manner.

172.



173.



ANGLE OF FRICTION. Fr., *Angle de frottement*; Ger., *Reibungswinkel*; Ital., *Angolo d'attrito*; Span., *Anjulo de rozamiento*.

The angle of friction is also called the *angle of repose*. In an Arch, that angle at which the arch-stones cease to have any tendency to slip from their own weight or to exert any thrust on the pier. Rondelet found by repeated experiments that even where the surfaces were wrought in the best manner the angle was seldom less than 28°, and it was in some cases as much as 36°. The angle varies with the weight as well as with the roughness of the stone. With soft stones the tendency to slide is greater than with hard stones, where the amount of roughness is the same, particularly where the weight is great, as the inequalities are broken down when the stone is soft, and the dust facilitates sliding.

On Roads and Railways it is that inclination or gradient at which the carriages are on the point of moving by their own gravity; it varies with the roughness or smoothness of the road or rails, and with the diameter and friction of the wheels upon their axles. (See Morin, 'Nouvelles Expériences sur le Frottement.')

The following, from Poncelet and others, show the relative angle of repose on various kinds of roads and railways:—

| Wheels with iron tires on a— | Ratio of Slope. | Wheels with iron tires on— | Ratio of Slope. |
|---|---|---|---|
| Road of sand and gravel .. .. | 1 in 16 | Oak planks, not planed .. .. .. | 1 in 98 |
| „ of broken stone in ordinary condition | 1 „ 25 | Stone trackway, well laid .. .. | 1 „ 179 |
| „ of broken stone in perfect condition | 1 „ 67 | Railway .. .. .. .. .. .. | 1 „ 280 |
| Well-made pavement .. .. .. | 1 „ 71 | An iron-shod sledge on hardened snow | 1 „ 30 |

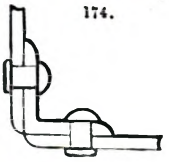
For further information on this subject, see Friction.

**ANGLE-IRON.** Fr., *Cornière, ou Fer de cornière*; Ger., *Winkel, oder Eckeisen*; Ital., *Ferro d'angolo*; Span., *Hierro angular*.

Any rolled bar of iron, Figs. 174, 175, 176, 177, of an angular shape, is usually termed *angle-iron*; it is employed for forming the edges of iron-safes, bridges, and ships; or to be riveted to the corners of boilers, tanks, &c., to connect the side-plates. See Boilers; Bridges; Iron-Ship Building.

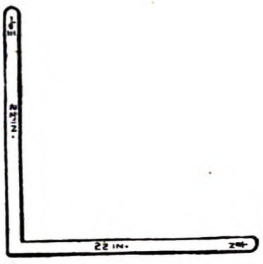
When we treat of the different structures in which angle-iron is employed, we will discuss the strength, suitable form, dimensions, and other mechanical properties of *angle-iron*; here we merely give cross-sections, dimensions, and weights of some of the principal forms manufactured in the Earl of Dudley's extensive works at Round Oak, near Dudley. For *Tee* and angle iron, Kirkaldy lately found that the specific gravity varied from 7·7310 to 7·5297, and he took 7·6006 as the mean result of ten experiments. Whence if the area, in square inches, of the cross-section of any specimen of angle or of T iron be multiplied by 3·29887 (3·3 nearly), the product will give the weight of a lineal foot of such specimen in pounds. For example, Fig. 179 is the cross-section of one of a series of angle-irons of the Round Oak Works; length of each side = 6 in. mean breadth = 1 in.; area = 11 sq. in.; therefore $11 \times 3{\cdot}29887 = 36{\cdot}28757$ lbs. the lineal foot, or $36\frac{1}{4}$ lbs. nearly. The mean breadth of this series varies from $\frac{5}{8}$ to 1 in. However, it is necessary to state that a lineal foot of this iron, Fig. 179, weighed 38 lbs.

174.



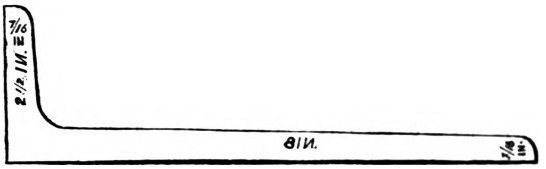
175.

Length of sides, $2\frac{1}{2}$ and $2\frac{1}{2}$; breadth, $\frac{1}{8}$ in. Weight the lineal foot, 2 lbs. 2 oz.



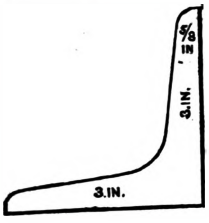

176.

$2\frac{1}{2}$ and 8; breadth, $\frac{7}{16}$ in. Weight the lineal foot, 17·5 lbs.



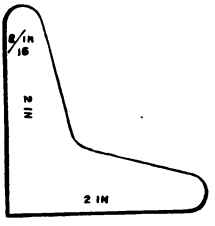

177.

3 and 3; breadth, $\frac{5}{8}$ in. Weight 12 lbs. the lineal foot.

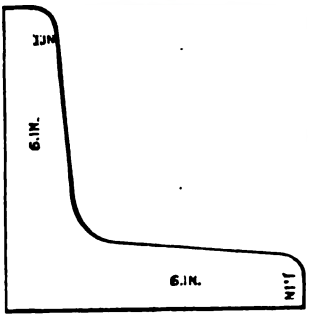



178.

2 and 2; mean breadth, $\frac{5}{16}$ in. Weight 5 lbs. 4 oz. the lineal foot.

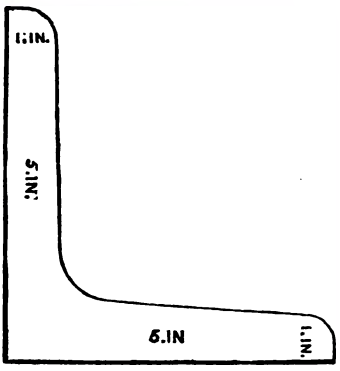



179.



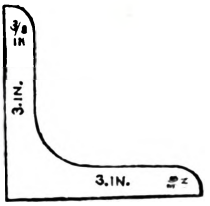

180.

Length of sides, 5 and 5; breadth, 1 in. Weight the lineal foot, 31·25 lbs.



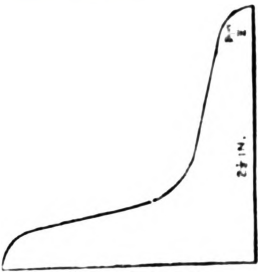

181.

Length of sides, 3 and 3; breadth, $\frac{3}{8}$ in. Weight the lineal foot, 7·5 lbs.




182.

Length of sides, $2\frac{1}{2}$ and $2\frac{1}{2}$; breadth, $\frac{5}{16}$. Weight the lineal foot, 5 lbs. 12 oz.

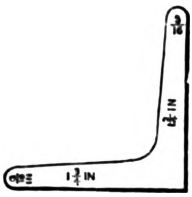


183.

Length of sides, 4 and 2, breadth, $\frac{1}{8}$ in. Weight of lineal foot, 9·5 lbs.

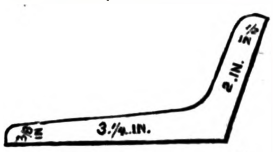
184.

Length of sides, $1\frac{3}{4}$ and $1\frac{3}{4}$; breadth, $\frac{3}{16}$ in. Weight of lineal foot, 2 lbs. $6\frac{1}{2}$ oz.



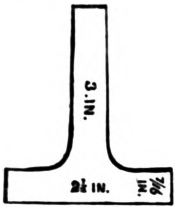

185.

Length of sides, $3\frac{1}{2}$ and 2; breadths, $\frac{3}{8}$ in. and $\frac{1}{2}$ in. respectively. Weight the lineal foot, 7 lbs.




186. T-iron.

Length: web, 3 in.; flange, $2\frac{1}{2}$ in.; thickness, $\frac{1}{16}$. Weight the lineal foot, 7·25 lbs.

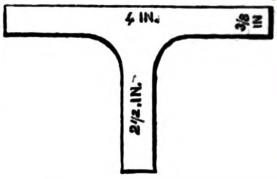



187. Section.

Weight the lineal foot, 3 lbs.

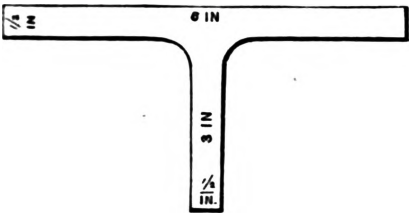
188. T-iron.

Length: web, $2\frac{1}{2}$; flange, 4; breadth, $\frac{3}{8}$ in. Weight the lineal foot, 8·5 lbs.



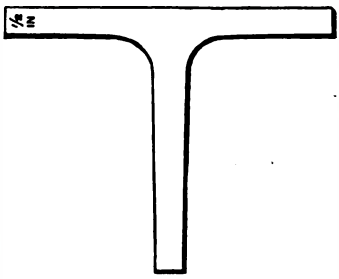

189. T-iron.

Length: web, 3; flange, 6; breadth, $\frac{1}{2}$ in. Weight the lineal foot, 15 lbs.



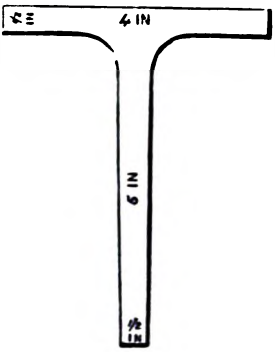

190. T.

Length: web, 4; flange, 5; breadth, $\frac{1}{2}$ in. Weight the lineal foot, 14·5 lbs.



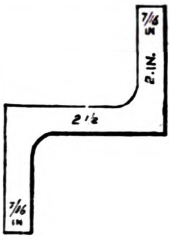
191. T. Section.

Length: web, 5; flange, 4; breadth, $\frac{1}{2}$ in. Weight the lineal foot, 16 lbs.



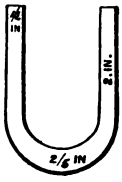

192. Section.

Length of each arm, 2 in.; web, $2\frac{1}{2}$; breadth, $\frac{7}{16}$ in. Weight the lineal foot, 8 lbs. 2 oz.



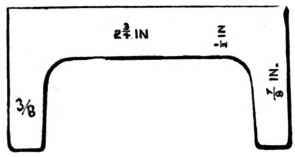

193. Section.

Length of each arm, 2 in.; breadth varying uniformly from ·4 in. to ·25 in. Weight the lineal foot, 5·75 lbs.



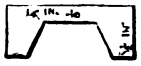
194. Section.

Length of each arm, $\frac{7}{8}$ in.; web, 2·75 in.; breadth varying from $\frac{1}{2}$ in. to $\frac{3}{8}$ in. Weight the lineal foot, 6 lbs. 14 oz.



195. Section.

Length of each arm, $\frac{1}{2}$ in.; least breadth, $\frac{1}{4}$ in.; web, $1\frac{1}{2}$ in.; $\frac{1}{8}$ in. thick. Weight the lineal foot, 1 lb. 6 oz.



196. Section.

Length of each arm, $\frac{3}{4}$ in.; web, 1 in.; breadth, $\frac{1}{8}$ in. Weight the lineal foot, 11 oz.

197. Section.

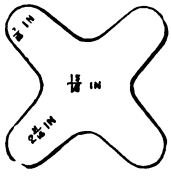
Length, $1\frac{3}{4}$ in.; breadth, $\frac{3}{4}$ in. Weight the lineal foot, 3 lbs. $15\frac{3}{4}$ oz.

198. Section.

$\frac{1}{2}$ in. thick; the other dimensions are given on the section. Weight the lineal foot, 1 lb. 5 oz.

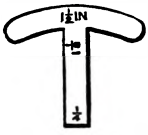
199. Section.

$\frac{15}{16}$ in. thick; the other dimensions are given on the section. Weight the lineal foot, 5 lbs. $1\frac{1}{4}$ oz.



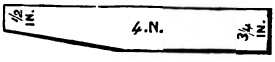
200. Section.

$\frac{1}{4}$ in. thick. Weight the lineal foot, 2 lbs.



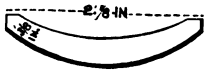
201. Section.

Length, 4 in.; breadth varying from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. Weight, 9 lbs.



202. Section.

$\frac{3}{8}$ in. thick; chord, $2\frac{1}{8}$ in., as shown on the section. Weight the lineal foot, 3 lbs. 4 oz.



**ANGLE-RIDGE.** Fr., *Arêtier*; Ger., *Gradsparre.*

*Angle-rafter*, more commonly called "hip-rafter," in hipped roofs is the piece of timber which runs from the angle of the building to the ridge of the roof into which it is framed, and of which it forms the continuation to the eaves, where it butts on the *dragon-piece*. It is usually from $1\frac{1}{2}$ inch to 2 inches thick, and from 6 inches to 8 inches deep, according to the length; the ends of the jack-rafters are nailed to it in the same manner as the common rafters are nailed to the ridge.

**ANGLE OF REPOSE.** Fr., *Angle de repos*; Ger., *Ruhewinkel*; Ital., *Angolo limite d'attrito*; Span., *Angulo de reposo.*

See Angle of Friction.

**ANGLE-STAFF.** Fr., *Corniche de cornière*; Ger., *Winkel Karniess*; Span., *Guarda-arista.*

The strips of wood employed in the inside of buildings, upon the exterior vertical angles, to protect the plastering, are called angle-staffs.

Angle-staffs are of two kinds, namely, square staffs and round staffs, also called *angle-beads*, the former being mostly employed when the walls are papered over, and the latter when the angles are seen.

**ANGLE-TIE.** Fr., *Attache angulaire*; Ger., *Winkel Strebe*; Ital., *Calastrello d'angolo, Traversa*; Span., *Tirante.*

See Angle-Brace.

**ANGLE OF TRACTION.** Fr., *Angle de traction*; Ger., *Zug-Winkel*; Ital., *Angolo di trazione*; Span., *Angulo de traccion.*

The angle formed by the inclination of the traces with the surface of the roadway is termed the angle of traction.

**ANGULAR MOTION, OR VELOCITY.** Fr., *Mouvement angulaire*; Ger., *Winkelbewegung oder Winkelgeschwindigkeit*: Span., *Velocidad angular.*

The velocity of a point moving in a circle, whose radius is taken as a unit, is measured by the length of the arc that may be described by the point in a given time; but this arc measures an angle, and that angular measure is termed the angular velocity. As it is a part of our design to generalize and follow principle wherever it lead us, when such generalization tend to important practical results; hence, we purpose to explain angular velocity in general terms.

In calculating the motions of geared machinery, the angular velocity of a body has often to be determined when the number of rotations ($n$) in a minute is given. The distance traversed by the

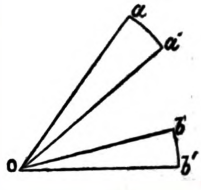
point situated 1 foot from the axis is $2\pi$ for each revolution, consequently $2n\pi$ for $n$ revolutions, that is, $2n\pi$ in 1 minute, or 60 seconds. The distance traversed by this point in 1 second is therefore $\frac{2n\pi}{60}$ or $\frac{n\pi}{30}$, which is the angular velocity required. If we call this angular velocity $\omega$, $\omega = \frac{n\pi}{30}$; that is, *to obtain the angular velocity, multiply the number of revolutions a-minute by the ratio of the circumference to the diameter, and divide the product by* 30. If, for instance, a wheel makes 45 revolutions a-minute, its angular velocity is $\omega = \frac{45 \times 3{\cdot}1416}{30} = 4{\cdot}7124$. From this formula is deduced $n = \frac{30\,\omega}{\pi}$; that is, *to find the number of revolutions a-minute, multiply the angular velocity by* 30, *and divide by the ratio of the circumference to the diameter.* For instance, if $\omega = 5$ $n = \frac{5 \times 30}{3{\cdot}1416} = 47{\cdot}7$, or about 48 revolutions a-minute.

The motion of rotation signifies the movement which all points of a single body make, in describing arcs or circles round the same axis, when the planes are perpendicular to that axis, and retain the same distance from each other.

Such is the movement of a cog-wheel or fly-wheel, and of all revolving parts of machines.

The first property peculiar to this species of motion is, that *all points of a body describe in the same time arcs of the same number of degrees.* Let us suppose the axis of rotation to be perpendicular to the plane of Fig. 203, and let O be the point where it meets this plane. Let us take any point; for instance, A; let $a$ be the projection, upon the plane of the figure, of the initial position of the point A, and let $a'$ be the projection of its position at the end of the time $t$; the arc described by the point A will be equal to the arc $a\,a'$, having O for its centre. Let B be another point of the body; $b$, the projection of its first position; $b'$, the projection of its final position; and $b\,b'$, the projection of the arc, which it has described. Unite O$a$, O$a'$, O$b$, O$b'$. O$a'$ will be the position of A with regard to the axis after the space of time $t$ and O$a$ before the first instant. From the point B to the axis also draw a line. O$b$ will be its position before the first instant, and O$b'$ after the lapse of the time $t$. Therefore the points A and B will maintain their relative positions; the angle formed by the two planes drawn from A and B remains unchanged. But this angle measures at the first instant $a\,O\,b$, and at the final instant $a'\,O\,b'$; therefore these two angles are equal. If we cancel the common part $a'\,O\,b$, there remains $a\,O\,a' = b\,O\,b'$. Therefore the arcs $a\,a'$ and $b\,b'$ are the arcs corresponding to the equal angles at the centre, which have the same number of degrees. The same may be said of all points of the body, as A and B are taken indiscriminately.

203.




It therefore follows that *the velocities of different points of the body, at the same instant, are proportional to their distances from the axis of rotation.* Suppose, for instance, that the arcs $a\,a'$ and $b\,b'$ have been described in a very short time $\Delta t$. The similitude of these arcs gives the proportion $a\,a' : b\,b' = O\,a : O\,b$, from which is derived $\frac{a\,a'}{\Delta t} : \frac{b\,b'}{\Delta t} = O\,a : O\,b$. $\frac{a\,a'}{\Delta t}$ and $\frac{b\,b'}{\Delta t}$ show respectively the velocity of the points A and B. By calling the distances O$a$ and O$b$, $r$ and $r'$, and the velocities $v$ and $v'$, the result will be, $v : v' = r : r'$.

II. To determine completely the motion of a body turning round an axis, it is sufficient to know the motion of one of its points. The motions of all points of a body are generally compared to that of one particular point, 1 foot, or 1 mètre, distant from the axis. The motion of this point is generally called, as previously stated, the *angular velocity*, and is usually expressed by the letter $\omega$. On comparing the velocity of any point A to that of the point situated at the unity of distance from the axis, we get, in accordance with the rule explained above, $v : \omega = r : 1$ or $v = \omega r$; that is, *the velocity of any point of a body is equal to the angular velocity multiplied by the distance of that point from the axis of rotation.* If, for instance, the *angular velocity* be 3, the velocity of a point, situate at 0·40 ft. from the axis, would be $v = 0{\cdot}40$ ft. $\times\ 3 = 1{\cdot}20$ ft., from which is drawn the formula $\omega = \frac{v}{r}$; that is, *the angular velocity is obtained by dividing the velocity of any point by the distance of that point from the axis.* For instance, let us seek the angular velocity of the earth. R is the radius of the equator; the velocity of a point situated on this circle is therefore $\frac{2\pi R}{86400}$, there being 86400 seconds in 24 hours, the time employed by the point in one revolution. Divide this velocity by the distance R of the point under consideration from the axis, and the result will be the angular velocity $\omega = \frac{2\pi}{86400} = \frac{3{\cdot}1415926}{43200} = 0{\cdot}000072722$; consequently $r = \frac{v}{\omega}$; that is, *the distance of any point of a body from the axis is the quotient of the velocity of the point by the angular velocity.* If, for instance, $v = 1{\cdot}50$ ft. and $\omega = 0{\cdot}8$ ft., then $r = \frac{1{\cdot}50\text{ ft.}}{0{\cdot}8} = 1{\cdot}875$ ft.

When the angular velocity is constant, the rotary motion is uniform.

If the arc described by a point situate 1 foot, or 1 mètre, from the axis be $a$ at the beginning of the first instant, and $t$ the time employed in traversing that arc, $a = \omega t$.

If the angular velocity be variable, the limit between the *angular velocity* and the increase of the time is called *angular acceleration.* This *angular velocity* is generally represented by $\gamma = \frac{d\omega}{dt}$; and as $\omega$ is itself derived from the arc $a$, the acceleration is the second derivative of that arc;

$d\omega$ being put for an extremely small quantity termed the differential of $\omega$, and $dt$ for differential of $t$, which is an extremely short time.

When the angular acceleration is constant, $d\omega = \gamma\, dt$.

If $\omega_0$ be the primitive angular velocity, we obtain $\omega = \omega_0 + \gamma t$, whence $da = \omega_0\, dt + \gamma t\, dt$.

Supposing the arc $a$ to begin at the position occupied by the point at starting, by integrating, we find $a = \omega_0 t + \frac{1}{2}\gamma t^2$. In these two proportions, the formulas of *uniformly variating motion* are expressed.

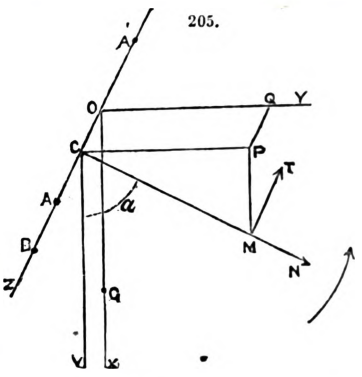
When several rotatory movements are to be considered, a geometrical sign is used to represent the *angular velocities*. On the axis of rotation an arbitrary point O, Fig. 204, is taken, and from this point is projected a length O P proportional to the angular velocity $\omega$. O P is placed in such a direction, that a spectator, placed at P and looking in the direction P O, sees the body turning in the direction of the hand of a watch; that is, if O P were horizontal, the movement above would be from left to right. O P′ would represent the angular velocity if the movement were in the opposite direction, namely, from left to right when passing underneath.

204.

It is therefore said that the angular velocity, or the rotation, *is represented in quantity and direction* by the line O P in the first instance, and O P′ in the second.

When a solid body revolves round an axis, through the action of any force, the reactions upon that axis can be determined. Let O Z, Fig. 205, be the axis of rotation connected with the points A and A, and with its extremity B, which rests against a perpendicular, fixed plane. From the centre of gravity G of the body pass a plane perpendicular to the axis, and cutting it at the point O; take the point O for the origin of the axes of the co-ordinates of the different points, the axis O Z for the axis of $z$, and two axes O X and O Y perpendicular to the first. Let M be any point of the body, $m$ its mass. From M draw upon the axis the perpendicular M C $= r$, and let $a$ be the angle it makes at the end of the time $t$, with a parallel C V to the axis $x$; and at the end of the same time let M P $= x$, C P $= y$, and P Q $= z$, be the co-ordinates of the point M. This point, rotating round O Z, describes a circle having C for centre. It may therefore be considered as being acted upon by a tangental force T and by a normal force N, the powers of which are respectively $T = m r \frac{d\omega}{dt}$ and $N = m\omega^2 r$, if the angular velocity be $\omega$ at the end of the time $t$. As the same may be said of all other points of the system, it follows that the body may be regarded as entirely subject to forces analogous to T and to forces analogous to N. The body is therefore moved in reality by a system of forces F, F′, F″, &c., the reactions of supports and the mutual action exercised by the material points of the body. The system of forces F and of the mutual actions is therefore equivalent (see *Equivalent* Forces) to the system of forces analogous to T and N. There must therefore be equality between the sum of the projections of these two systems of forces on each of the three axes, and between the sum of their momentums with regard to these axes.

205.




The projections of the force T on the axes of $x$, $y$, and $z$, are respectively

$$-\mathrm{T}\sin.\, a, \quad +\mathrm{T}\cos.\, a, \quad \text{zero}; \quad \text{or,} \quad -my\frac{d\omega}{dt}, \quad +mx\frac{d\omega}{dt}, \quad \text{zero}.$$

The relation of the momentums to the same axes is, adopting the conventional signs with regard to momentum,

$$-\mathrm{T}\cos.\, a.z, \quad -\mathrm{T}\sin.\, a\, z, \quad +\mathrm{T}\, r; \quad \text{or,} \quad -mxz\frac{d\omega}{dt}, \quad -myz\frac{d\omega}{dt}, \quad +mr^2\frac{d\omega}{dt}.$$

The projections of the force N are,

$$+\mathrm{N}\cos.\, a, \quad +\mathrm{N}\sin.\, a, \quad \text{zero}; \quad \text{or,} \quad +m\omega^2 a + m\omega^2 y, \quad \text{zero}.$$

The momentums of the same force with regard to the same axes are expressed,

$$-\mathrm{N}\sin.\, a.z, \quad +\mathrm{N}\cos.\, a.z, \quad \text{zero}; \quad \text{or,} \quad -m\omega^2 yz, \quad +m\omega^2 xz, \quad \text{zero}.$$

In passing from M to another point of the body, $x$, $y$, $z$, $r$, and $a$, will change; but $\omega$ and $\frac{d\omega}{dt}$ will remain the same. On the other hand, the mutual forces will disappear when the sum of their projections on to any axis is nought, as they are equal and opposed to each other; the sum of their momentums, with regard to an axis, will also be nought, for the same reason.

Let R be the reaction exercised upon the point A perpendicular to the axis, omitting friction, and R′ the same reaction upon A′; and S the reaction exercised by a point B in the direction of the axis. O A $= h$ and O A′ $= h'$; we can then describe the six conditions of equivalence; putting $\Sigma$ for sum, $\Sigma\, m\, x$ signifies the sum of the products $m\, x$, then,

$$\Sigma\, \mathrm{F}_x + \mathrm{R}_x + \mathrm{R}'_x = -\frac{d\omega}{dt}\, \Sigma\, m\, y + \omega^2\, \Sigma\, m\, x, \qquad [1]$$

$$\Sigma\, \mathrm{F}_y + \mathrm{R}_y + \mathrm{R}'_y = +\frac{d\omega}{dt}\, \Sigma\, m\, x + \omega^2\, \Sigma\, m\, y, \qquad [2]$$

$$\Sigma\, \mathrm{F}_z + \mathrm{S} = 0, \qquad [3]$$

$$\Sigma\, \mathfrak{M}_x\, \mathrm{F} - \mathrm{R}_y \,.\, h + \mathrm{R}'_y \,.\, h' = -\frac{d\omega}{dt}\, \Sigma\, m\, x\, z - \omega^2\, \Sigma\, m\, y\, z, \qquad [4]$$

$$\Sigma \mathfrak{M}_z F + R_x h - R'_x . h' = - \frac{d\omega}{dt} \Sigma m y z + \omega^2 \Sigma m x z, \qquad [5]$$

$$\Sigma \mathfrak{M}_z F = \frac{d\omega}{dt} \Sigma m r^2. \qquad [6]$$

The last equation gives $\frac{d\omega}{dt} = \frac{\Sigma \mathfrak{M}_z F}{\Sigma m r^2}$; that is, *the angular accceleration is expressed by the sum of the momentums of the forces with regard to the axis of rotation, divided by the vis inertia of the body with regard to the same axis*, which expression can also be arrived at in a shorter manner. The first five equations make known the five unknown quantities, $R_x$, $R_y$, $R'_x$, $R'_y$, and S; from the equations [1] and [5] $R_x$ and $R'_x$ may be found, and from [2] and [4] $R_y$ and $R'_y$ are deduced. Equation [3] will give the value of S.

If the movement is reckoned only for the first instant (it can also be another space of time), the axis of $x$ can be passed through the centre of gravity. If we call M the total mass of the body and $a$ the distance of the centre of gravity from the axis O Z, $\Sigma m x = M a$ and $\Sigma m y = 0$.

If, again, we suppose the body symmetrical with regard to the plane X O Z, we get $\Sigma m x z = 0$ and $\Sigma m y z = 0$; and the six equations of the problem become

$$\Sigma F_x + R_x + R'_x = M \omega^2 a,$$

$$\Sigma F_y + R_y + R'_y = M a \frac{d\omega}{dt}, \quad \Sigma_z + S = 0,$$

$$\Sigma \mathfrak{M}_x F - R_y h + R'_y h = 0,$$

$$\Sigma \mathfrak{M}_y F + R_x h - R'_x h' = 0,$$

$$\Sigma \mathfrak{M}_z F = \frac{d\omega}{dt} \Sigma m r^2.$$

The quantities $M a \frac{d\omega}{dt}$, $M \omega^2 a$ express the tangental force and the normal force of the centre of gravity, considered as a material point where all the mass M is concentrated.

Two particular cases deserve consideration:—1. Where the axis of rotation is horizontal, the body has its centre of gravity in that axis, and is subject to no external force except that of gravitation. 2. When the axis of rotation is vertical, and the body, having its centre of gravity in the axis, is only subject to the force of gravitation and to forces acting horizontally.

1. In the first case we get

$$a = 0, \Sigma F_x = P, \Sigma F_y = 0, \text{ and } \Sigma F_z = 0,$$
$$\Sigma \mathfrak{M}_x F = 0, \Sigma \mathfrak{M}_y F = 0, \Sigma \mathfrak{M}_z F = 0,$$
$$R_x + R'_x = - P, R_y + R'_y = 0, S = 0.$$

The sixth equation gives $\frac{d\omega}{dt} = 0$, from which it follows that the movement is uniform; the equations [4] and [5] can be reduced to

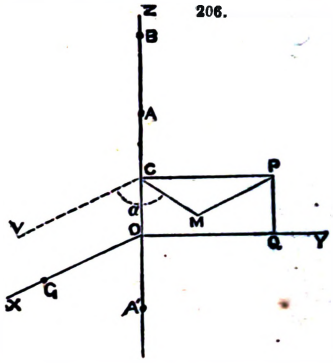
$$- R_y . h + R'_y h' = - \omega^2 \Sigma m y z,$$
$$R_x . h - R_x . h = + \omega^2 \Sigma m x z;$$

or, if the plan X O Z were symmetrical,

$$R_y . h = R'_y h' \text{ and } R_x . h = R'_x . h'.$$

The first of these, compared with the second equation, gives $R_y = 0$ and $R'_y = 0$; that is, the reactions at A and A' are then vertical.

2. In the second case suppose the axis O Z, Fig. 206, to be vertical, and the centre of gravity to be situated in the axis O X at the first instant, P to be the weight of the body, and that we have as above $\Sigma m y = 0$ and $\Sigma m x = M a$, we find



206.

$$R_x + R'_x = \omega^2 M a,$$

$$R_y + R'_y = M a \frac{d\omega}{dt},$$

$$- P + S = 0,$$

$$- R_y . h + R'_y . h' = - \frac{d\omega}{dt} \Sigma m x z - \omega^2, \Sigma m y z,$$

$$P a + R_x . h - R'_x . h = - \frac{d\omega}{dt} \Sigma m y z + \omega^2, \Sigma m x z,$$

$$\Sigma \mathfrak{M}_z F = \frac{d\omega}{dt} \Sigma m r^2.$$

If we wish the reactions of R and R' to be nought, we must according to the two first equations, make $a = 0$, that is, the centre of gravity must be in the axis of rotation. The equation $- P + S = 0$ gives $S = P$; that is, the charge of the pivot which sustains the axis of rotation is equal to the weight of the body. The two following equations can be reduced to

$$\frac{d\omega}{dt} \Sigma m x z + \omega^2, \Sigma m y x = 0,$$

$$\text{and } \frac{d\omega}{dt} \Sigma m y z - \omega^2, \Sigma m x z = 0;$$

from which follows $\Sigma m x z = 0$ and $\Sigma m y z = 0$; that is, the axis of rotation is one of the principal axes of the body.

In millstones these two conditions are fulfilled by means of lead introduced into vertical holes made for that purpose. If this were not done, it might happen that, although remaining horizontal when at rest, they may, when in motion, exercise lateral reactions upon this axis, and cease to be horizontal.

*General Conditions of the Uniformity of Motion or of Equilibrium of a Solid Body, Free in Space, and subjected to any Forces.*—It is evident that a solid body, entirely free, can receive and take but one of the three following motions:—A motion of translation without rotation, a motion of rotation without translation, and a simultaneous motion of translation and rotation.

Every motion of translation may be resolved into three other motions similar in relation to any three rectangular axes drawn in space; and it is evident that if each of these component motions is separately zero, the resultant motion of translation will be so likewise. This condition is, moreover, necessary and sufficient.

Now, in order that these three motions shall be zero for each of these axes, the sums of the components parallel to the axes should separately be zero. Then, if we call X, Y, and Z, the sums of the components of the exterior forces applied to an invariable solid, these forces cannot impart a motion of translation if we have at the same time $X = 0$, $Y = 0$, $Z = 0$, and the motion will remain uniform or the body be in equilibrium as to translation.

So also every motion of rotation of a body, or of material points composing it, may be resolved into three motions of rotation around three rectangular axes drawn through any point. In order that the body shall receive no motion of rotation, it is only requisite that the rotations around each of the three axes shall be separately zero, which requires the sums of the moments (not momentums) of forces in relation to each of the three axes, that is, the sums of the masses or weights multiplied by their perpendicular distances, to be separately zero, so that if we call L, M, and N, these three sums, we must have at the same time $L = 0$, $M = 0$, $N = 0$. When these conditions are satisfied, the work developed in imparting a motion of rotation will be zero, and it will continue to move uniformly or will rest in equilibrium.

In order that the body receive no motion of translation, nor of rotation, or that its motion be in no wise altered, all that is requisite is: 1st. That the sum of all the components of the forces soliciting the body, in relation to any three rectangular axes, shall be separately zero. This is expressed by the relations

$$X = 0,\ Y = 0,\ Z = 0,$$
$$L = 0,\ M = 0,\ N = 0,$$

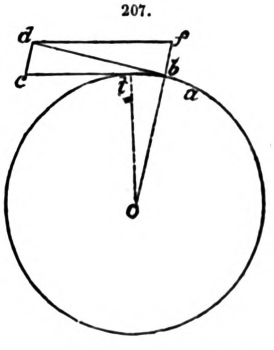
which we call the six equations of uniform motion, or the equilibrium of an invariable body, free and solicited by any forces.

*Centrifugal Force.*—It is well known that, if we tie a stone or other heavy body to a cord, impress it with a circular motion of which the hand is the centre, the cord will experience a tension, the greater as the motion is more rapid. From observation of this fact came the use of the sling as an implement of war among the ancients, and which is now but a boy's play. Similar effects are seen in waggons running swiftly in short curves, in circuses, when the horses and riders are naturally induced to lean towards the centre of the curves they describe to prevent being overthrown. The reader may readily find other effects from the same cause: all of them prove that in curvilinear motion the bodies are subjected to a peculiar force tending to drive them from the centre, which force is called the *centrifugal force.*

*Measure of the Centrifugal Force.*—To understand what takes place when a material point is submitted to the action of the centrifugal force, let us examine, first, how this force is developed in circular motions. When a material point or an elementary mass $m$ passes from one element of a curve which it describes to another, it tends by virtue of its inertia to continue its motion in the direction of the prolongation of this element, or of the tangent $b\,d$ of the curve, and is what is termed *flying off at a tangent*, as is the case with the sling at the moment one suddenly lets go his hold upon the cord. If the mass $m$ takes the direction of the next element, it is then retained upon the curve, either by the resistance of the curve itself, upon which it then exerts a pressure, or by the tension which it develops in the cord. This pressure or tension is itself the measure of the centrifugal force, in contradistinction to which it is sometimes called the centripetal force.

This force is in the direction of the radius of the curve or of the corresponding circle, and if we call V the velocity with which the mass $m$ is impressed in the direction of $a\,b$, and take the length $b\,d$ to represent it, it is clear that the velocity destroyed by the resistance of the cord or the centripetal force, will be represented by the side $d\,c$ of the parallelogram $b\,c\,d\,f$, whose side $d\,c$ is parallel to the radius $o\,b$, in the direction of which this force is exerted. Now, an inspection of the figure shows that the angles $a\,b\,O$ and $b\,d\,c$ are equal as internal and external, and the angles $d\,c\,b$ and $c\,b\,O$ as alternate and internal; and as moreover the angles $c\,b\,O$ and $a\,b\,O$ being formed on both sides of the radius by two equal and consecutive elements of the circle or of the polygon whose infinite number of sides replace it, it follows that the angles $b\,d\,c$ and $d\,c\,b$ are equal, and the triangle $b\,d\,c$ is isosceles. Then the velocity $b\,a$ with which the mass $m$ is moved in the direction of the following elements $b\,t$, is the same as that it had in the direction of the preceding element. Thus, *in circular motion, the centrifugal force does not alter the velocity of rotation;* which is conformable with the *principle of work*, since this force, in the direction of the radius, or normal to the path described, produces no work in the direction of motion, so long as there is no path described in its own direction and by its action.

207.




This being settled, the velocity destroyed in the element of time $t$ by the centripetal force has, according to the figure,

$dc$ for its measure, and the centripetal and centrifugal forces, which are equal and directly opposite, have for a common measure $F = m \cdot \frac{c}{t}$.

Now, the triangle $bdc$ and $Obt$ having equal angles, are similar; we have then $bO : bt :: bd : dc$, whence $dc = \frac{bd \times bt}{bO} = \frac{Vs}{R}$. In calling R the radius of the circle described, and $s$ the elementary arc run over in the element of time $t$; and as we have $V = \frac{s}{t}$ or $s = Vt$, it follows that $dc = \frac{V \times Vt}{R} = \frac{V^2 t}{R}$; and finally, that the centrifugal force has for its measure $F = \frac{mV^2 t}{R.t} = m\frac{V^2}{R}$; if, moreover, we call $V_1$ the angular velocity, or that at the unit of distance, we have $V = V_1 R$, and the expression for the centrifugal force becomes $F = m\frac{V_1^2 R^2}{R} = mV_1^2 R$.

What we have said of the centrifugal force applies to a material point describing any curved line, since in each of its positions an osculating circle may be substituted for the curve; the only difference being in the fact that the radius R of this circle varies for each position of the moving body, while that in the circle is constant.

*Work Developed by the Centrifugal Force.*—When instead of being retained by a circular curve or at a constant distance from the centre of rotation, the material point is removed farther from it, the centrifugal force will cause it to describe a certain path in the direction of the radius; it develops upon this body a work easily appreciated. In fact, if in an element of time the material point is displaced in the direction of the radius by a certain elementary quantity V, the corresponding work of the centrifugal force will be $Fr = mV_1^2 R\, r$, and the total work due to this force, when the material point shall have passed from R'' to R' at a greater distance from the centre, will be given by the sum of all the analogous elementary works taken from $R = R''$ to $R = R'$. Now we see from *the principle of work* that this sum is equal to $\frac{1}{2} mV_1^2 (R'^2 - R''^2) = \frac{1}{2} m (V'^2 - V''^2)$ if we call $V' = V_1 R'$ and $V'' = V_1 R''$, the velocities of rotation of the point around the centre. We have then for the work of the centrifugal force $T = \frac{1}{2} mV_1^2 (R'^2 - R''^2) = \frac{1}{2} m (V'^2 - V''^2)$.

We remark that the second member of this relation is no other than the variation of the *vis viva* of rotation, experienced by the material point while partaking of this motion in its removal from the centre of rotation, whatever may be the curve or path described in this removal. This expression then could be directly deduced from the principle of *vis viva*.

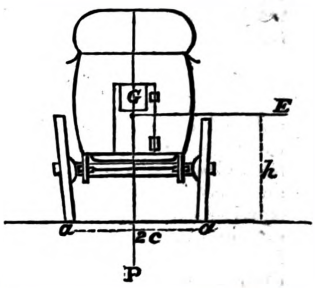
In the case just considered, the centrifugal force tends to increase the absolute velocity of the body moved, and acts thus as a motive force which is developed in the motion of rotation. When, on the other hand, the body approaches the centre, the centrifugal force is opposed to it, and acts as a resistance in developing a work having indeed the same expression, but which is resistant, since the path described is in a direction contrary to the action of the force.

The preceding considerations will find their application in the study of the effects of certain hydraulic receivers.

*Action of the Centrifugal Force upon Waggons.*—When a coach with great speed turns upon a short curve, the effects of the centrifugal force is felt by the passengers, who are driven towards the outer curve with an intensity often dangerous for those placed on the outside, and which may even disturb the stability of the coach itself.

There is often a prejudice against the effects of this force upon railways, when it is proposed to use curves of small radius; but it is easily shown by figures, that in this regard the greatest velocities with the common radii of curves produce no danger.

208.




In fact, calling P the weight of the car or any carriage, $h$ the height of its centre of gravity above the plane of the track, $F = \frac{P}{g} V_1^2 R$ the centrifugal force, $2c$ the width of the track. It is evident that when the car passes around the centre O of the curve, and is arrested by some obstacle, such as the falling or rising of the rail, it tends to upset outwards, in turning around the point $a$ of instantaneous support. This motion is counterbalanced by the weight P of the carriage, and at the moment when the weight and centrifugal force are in equilibrium as to the point, we have between the moments of the two forces P and $F = \frac{P}{g} V_1^2 R$ the relation $Pc = \frac{P}{g} V_1^2 R h$, which shows that, with equal velocities and weights, the stability of the car will be so much the greater, and the equilibrium better secured, as the width $2c$ of the track is greater in its ratio with the height of the centre of gravity. The velocity of transit answering to this equilibrium upon common tracks, for which $2c = 4{\cdot}75$ ft. with cars whose centre of gravity when loaded is $3{\cdot}28$ ft. in height, and with curves 1312 ft. radius, will be given by the relation $V_1^2 R = \frac{gc}{h}$, whence $V_1 R = \sqrt{\frac{gc}{h}} R = 174{\cdot}9$ ft., a velocity beyond the greatest speed of railroads. This shows that in this regard the centrifugal force occasions no danger. But we should not forget that it brings the flanges of the outer wheels to bear against the rails, producing a cutting away which wears them out and greatly contributes to their running off the track.

*Action of the Centrifugal Force in Fly-wheels.*—For regulating the irregularities of machines we make use of rotating pieces of considerable weight and diameter, impressed with quite a great velocity, upon which the motion of rotation develops a centrifugal force of considerable intensity. Thus, for example, the fly-wheel of an iron rolling-mill, established at the iron-works of Fourchambault, weighs 13,232 lbs., its radius is 9·58 ft., the number of turns it makes is 60 in 1′, or 1 per second.

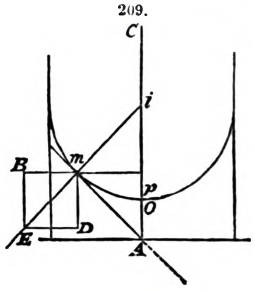
We have thus $V_1 = 6{\cdot}28$ ft. in 1″, and consequently, $V_1 R = 6{\cdot}28 \times 9{\cdot}58$.

If we consider a segment of the ring equal to $\frac{1}{6}$ of its circumference, corresponding to a single arm, its weight will be 2205 lbs.; and if its connection with the adjoining segment is broken, the arm will experience, in the direction of its length, a traction expressed by $\frac{2205}{32{\cdot}1817} \times 6{\cdot}28^2 \times 9{\cdot}58 = 25{,}887$ lbs., which shows that in fly-wheels the centrifugal force acquires a dangerous intensity, and that it is well to give great solidity to their connections. The velocity of rotation of these machines should be confined within certain limits. If, for example, we were to impart to the above fly a double velocity, or 120 turns in 1′, the centrifugal force of the segment just considered would be four-fold, or equal to 103,548 lbs.

*Application to the Motion of Water contained in a Vase turning round a Vertical Axis.*—In this case the liquid molecules are simultaneously subjected to the vertical action of their own weight, and to a centrifugal force developed horizontally; in order that they shall be in equilibrium under the action of these two forces, it is requisite that the resultant of these two forces should be normal to the surface assumed by the fluid mass, for if this resultant was inclined to the surface, the molecules would yield to its oblique action.

Let us consider a molecule $m$ with the weight $p$ and mass $\frac{p}{g}$, situated at the distance $mp = R$ from the axis of rotation A C. In a horizontal direction and perpendicular to the axis, it will be impressed with a centrifugal force expressed by $\frac{p}{g} V^2 R$. Let us take $mB = \frac{p}{g} V^2{}_1 R$, $mD = p$, and construct the parallelogram $mBED$, whose diagonal normal to the surface assumed by the fluid intersects the axis at $i$. The similar triangles $mpi$ and $mBE$ give us $mB$ or $\frac{p}{g} V_1{}^2 R : BE$ or $p :: mp$ or $R : pi$, whence $pi = \frac{g}{V_1{}^2}$

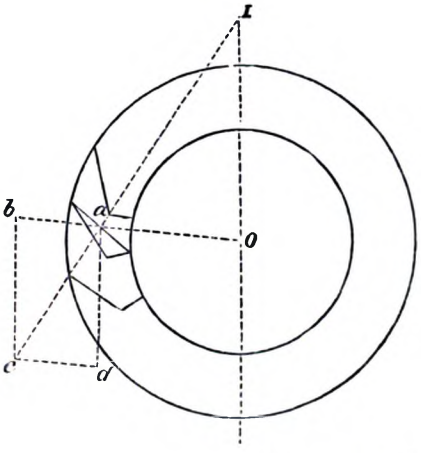
209.




Thus the distance $pi$, which is called the subnormal, depends only upon the constant number $g$, and the angular velocity supposed also to be constant. Consequently this distance is constant, which, according to the known properties of the parabola, shows that the generating curve of the surface of the level is a parabola whose summit is at the point O, and whose axis is that of the rotation, and we readily see that its parameter is $\frac{2g}{V_1{}^2}$, so long as we have $pp'$ or $2x : mp$ or $y :: mp$ or $y : pi$ or $\frac{g}{V_1{}^2}$, whence $y^2 = \frac{2g}{V_1{}^2} x$.

*Surface of Water contained in a Bucket of a Hydraulic-wheel with a Horizontal Axle.*—In following the reasoning of the preceding case, it is easy to see that, if we represent by $ab$ the centrifugal force $\frac{p}{g} V_1{}^2 R$, and by $ad$ the weight $p$ of any molecule situated on the surface, we shall have the proportion $ab$ or $\frac{p}{g} V_1{}^2 R : bc$ or $p :: R : OI$, whence $OI = \frac{g}{V_1{}^2}$; which shows that the distance OI is constant for all points of the surface of the liquid, and that consequently this surface is that of a cylinder, with a circular base of radius $aI$, whose axis is parallel to that of the wheel. This theorem, for which we are indebted to M. Poncelet, serves as the basis of the theory which this engineer has given upon the effects of water in bucket-wheels with great velocities.

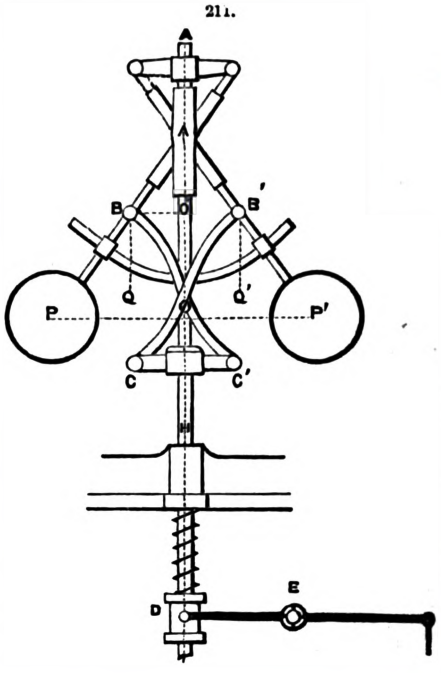
210.




*Regulators with Centrifugal Force.*—The action of centrifugal force is utilised in the construction of an apparatus called a governor. It consists principally of a vertical spindle A H, Fig. 211, which receives from the machine to be regulated a motion of rotation. Upon this spindle are suspended two rods A P and A P′ jointed at A, and terminated by the equal weights or bobs P and P′. At the two joints B and B′ of the rods A P and A P′ are jointed two other equal rods B C and B′O, forming with the first a lozenge, and which at their ends C and C′ are also jointed with a collar traversed by the vertical spindle with which it turns, having at the same time a motion of translation in the direction of the length of this spindle. This collar has a yoke in which is fastened the fork of a lever D E, which acts upon the throttle-valves for steam, or upon any other piece.

The working of this contrivance is readily understood. By the effect of the rotatory motion of the vertical spindle, the balls of the regulator are thrown outwards from the axis, and so raise the collar a certain height. If the machine has attained and preserves its normal velocity, the balls and the collar are held in the same position, because there is established a state of equilibrium between the centrifugal force and the weights of the different parts of the apparatus. When the velocity increases, the centrifugal force increases, tending to spread outwards the balls and to raise the collar, and consequently the lever D E. Inversely, if the velocity diminishes, the balls approach the spindle; the collar and the end of the lever D E are lowered.

211.




Let us examine the mechanical conditions of the action of this apparatus, and first suppose the collar C C', as well as the rods B C and B' C', to be in equilibrium with the lever D E, so that, neglecting friction, we may regard the rods A B and A B' as free to yield to the centrifugal force which tends to separate them, and to the weight of the balls which tends to bring them nearer to the spindle.

The centrifugal force of each ball is $\frac{P}{g} V_1^2 \times$ O P, and its moment in relation to the axis of joints A is $\frac{P}{g} V^2_1 \times O P \times A O$. The moment of the weight P of each ball in respect to the same axis is $P \times O P$. Consequently the condition of equilibrium of each is $\frac{P}{g} V_1^2 \times A O = P$, whence $\frac{V_1^2}{g} = \frac{1}{A O}$; which shows that the distance of the balls' separation from the spindle depends not upon their weight, but solely upon the angular velocity of rotation, and enables us to so dispose of the weight of the balls as to satisfy other conditions. If we call T the time of the revolutions of the balls around the vertical spindle, we have $V_1 T = 2\pi = 6{\cdot}28$, whence $V_1 = \frac{2\pi}{T}$, and consequently $\frac{4\pi^2}{g T^2} = \frac{1}{A O}$, whence $T = 2\pi\sqrt{\frac{O A}{g}}$, which is double the duration of oscillations of a pendulum having for its height the height A O, at which the balls would be raised to the normal velocity.

The above formula enables us to determine approximately the height A O at which the balls are raised with a given velocity, and thus to establish their mean position. It gives, in fact, $A O = \frac{g T^2}{4\pi^2} = 0{\cdot}81517\, T^2$. Thus for T = 1", A O = 0·81517 ft.; T = 2", A O = 3·2606 ft.

In this calculation we have neglected the weight and the centrifugal force of the rods A B and A B'.

The preceding remarks are not sufficient to ensure the action of the pendulum as a regulating apparatus, since it is a requisite that it should be able to move the lever D E and the parts for the distribution of the steam or water upon which this lever operates, or in other terms, it should be able to overcome the resistances experienced in the motion of the collar, when the balls are separated or brought nearer to each other. These resistances can be estimated or measured when the apparatus is constructed, and if we call 2 Q the vertical force applied to the collar in the direction of the vertical spindle, $V'_1 = (1 + n') V_1$ another angular velocity, greater, for example, than the mean velocity $V_1$ by a fraction $n'$ of the latter, it is easily seen that the force 2 Q can be resolved into two other forces parallel and equal to Q, applied at each of the joints B and B', and that then we shall have for the equilibrium corresponding to these new conditions, at the instant of its being broken, the relation $\frac{P}{g} V'^2_1 \times O P \times A O = P \times O P + Q \times B O'$. Calling $a$ the distance A B = A B' and $b$ the length A P = A P' of the rods to the centre of the balls, we remark that $b : a :: O P : B O'$, whence $B O' = \frac{a}{b} . O P$, and consequently $\frac{P V'^2_1}{g} . A O = P + Q . \frac{a}{b}$. We have previously found that the value of A O corresponding to the mean position of the balls was $A O = \frac{g}{V^2_1}$; the above relation becomes, then, $P \frac{V_1^2}{V^2_1} = P + Q \frac{a}{b}$, whence we derive $\frac{P}{Q} = \frac{a}{b} \frac{V^2_1}{V'^2_1 - V^2_1} = \frac{a}{b(2n' + n'^2)} = \frac{a}{2bn'}$, as long as $n'^2$ is very small compared with $n'$.

We also see, then, from these considerations, due to M. Poncelet, that there exists a necessary relation between the ratio of the weight of the balls to the resistance and the degree of regularity of which the apparatus is susceptible.

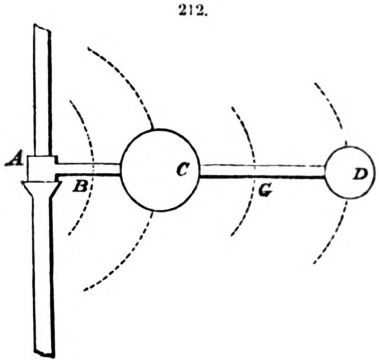
We see, also, that for a degree of regularity desired or considered as necessary in the operation of the machine, the weight of the balls increases proportionally with the resistance which the collar opposes or experiences. Then, for example, if we have the proportions $a = 0{\cdot}666$, and if we have

$n' = \frac{1}{50} = 0{:}02$, we find $\frac{P}{Q} = \frac{0{\cdot}66}{2 \times 0{\cdot}02} = 16{\cdot}5$, so that, if the resistance of the collar was only 22·05 lbs., the weight of each of the balls should be $P = 11{\cdot}03 \times 16{\cdot}5 = 181{\cdot}99$ lbs. This result shows that this apparatus cannot give a great degree of regularity to machines, without great dimensions and weights, if we would overcome, directly by the collar, considerable resistances.

It is from a disregard of these circumstances that many constructors have failed in the establishment of this kind of regulators, made for the purpose of raising sluice-gates, or in fixtures for the distribution of steam. This serious inconvenience may be avoided; and, with this simple and solid apparatus, we may obtain a proper regulation by arranging it in the manner which will be hereafter described. See GOVERNORS.

*How to Estimate the Units of Work in a Rotating Body.*—To take a simple case, let two balls, C and D, be connected by a rod, A D, and made to revolve round the centre, A; suppose C to weigh 50 lbs. and D 20 lbs.; the distance of C from A = 12 ft., and that of D = 27 ft. It is required to find the units of work in these balls when the point B, 1 ft. from the centre of motion A, moves at the rate of 19·3 ft. a-second.

212.




The *centre of gyration* is also required—that is, a point, G, in the rod where we may suppose the weight of the two balls collected—so that the amount of work may remain the same as when the bodies were apart.

Velocity of C = (19·3 × 12) feet a-second.

Velocity of D = (19·3 × 27) feet a-second.

Units of work in C = $\frac{(19{\cdot}3 \times 12)^2 \times 50}{64\frac{1}{3}} = 41688.$

Units of work in D = $\frac{(19{\cdot}3 \times 27)^2 \times 20}{64\frac{1}{3}} = 84418{\cdot}2.$

Total units of work = 126106·2.

Let $x$ be the distance, A G, then the work in the two balls collected at G = $\frac{(19{\cdot}3\,x)^2 \times 70}{64\frac{1}{3}} = 126106{\cdot}2.$ $\therefore\ x^2 = 311\frac{1}{7}$, and $x = 17{\cdot}639$ ft.

Now, if the two weights 20 + 50 = 70 lbs. be placed on the rod at the *centre of gyration* G, and move with a uniform velocity of (17·639 × 19·3) feet a-second, the amount of work in the bodies thus combined is the same as when posited at C and D.

From this simple case it is evident that when the *centre of gyration* of a rotating body is known, the accumulated work in that body is readily found. To find the *centre of gyration* in differently formed bodies requires the aid of a higher calculus, the introduction of which would be out of place in the present work. However, it is necessary to observe that the distance of this centre from the axis of rotation in a circular wheel of uniform thickness is equal to the radius of the wheel × $\sqrt{\frac{1}{2}}$; in a rod revolving about its extremity it is equal to the length of the rod × $\sqrt{\frac{1}{3}}$, and when the rod revolves about its centre it is equal to the length × $\sqrt{\frac{1}{12}}$; and in a plane rim, like the rim of a fly-wheel, it is equal to the square root of one-half the sum of the squares of the radii forming the ring.

*Question.*—The weight of a fly-wheel = 8000 lbs., suppose the centre of gyration to be 10 ft. from the axis, the diameter of which = 14 inches; the wheel makes 27 revolutions a-minute; how many revolutions will it make before it stops, the friction of the axis being $\frac{1}{5}$ of the whole weight?

Velocity of centre of gyration a-second = $\frac{20 \times 3{\cdot}1416 \times 27}{60} = 28{\cdot}2744$ ft.

Work in the wheel = $\frac{(28{\cdot}2744)^2 \times 8000}{64\frac{1}{3}} = 99411{\cdot}77.$

Circumference of the axis in feet = $\frac{14}{12} \times 3{\cdot}1416 = 3{\cdot}6652.$

Work destroyed in $x$ revolutions = $3{\cdot}6652 \times x \times \frac{8000}{5} = 5864{\cdot}32\,x.$ $\therefore\ x = \frac{99411{\cdot}77}{5864{\cdot}32} =$ 16·952 revolutions.

*Question.*—The weight of a fly-wheel is 1½ ton, the distance of the *centre of gyration* from the axis = 8 ft., and the number of revolutions a-minute = 24; what number of strokes will this wheel give two forge-hammers, each weighing 250 lbs., each hammer having a lift of 3 ft., friction being neglected?

Velocity of the centre of gyration = 20·1 ft. a-second. Work in the wheel = $\frac{(20{\cdot}1)^2 \times 3360}{64\frac{1}{3}} =$ 22984·6.

Work of $x$ lifts of the hammers = $250 \times 2 \times 3 \times x = 1500\,x.$ $\therefore\ 1500\,x = 22984{\cdot}6.$ $\therefore\ x =$ 15·3 lifts to each hammer.

*Question.*—The diameter of a grindstone is 5·6 ft., and its weight = 386 lbs.; the circumference is made to revolve with a velocity of 6 ft. a-second; the circumference of the axis = 8 inches, the friction of it = $\frac{1}{7}$ of the weight: find the number of revolutions made by the stone when left to itself?

The *centre of gyration* from the axis of the grindstone = $2{\cdot}8\sqrt{\frac{1}{2}}$.

To find the velocity of the centre of gyration, $\frac{5{\cdot}6}{2}$ : 6 : : $2{\cdot}8\sqrt{\frac{1}{2}}$ : $6\sqrt{\frac{1}{2}}$. The square of

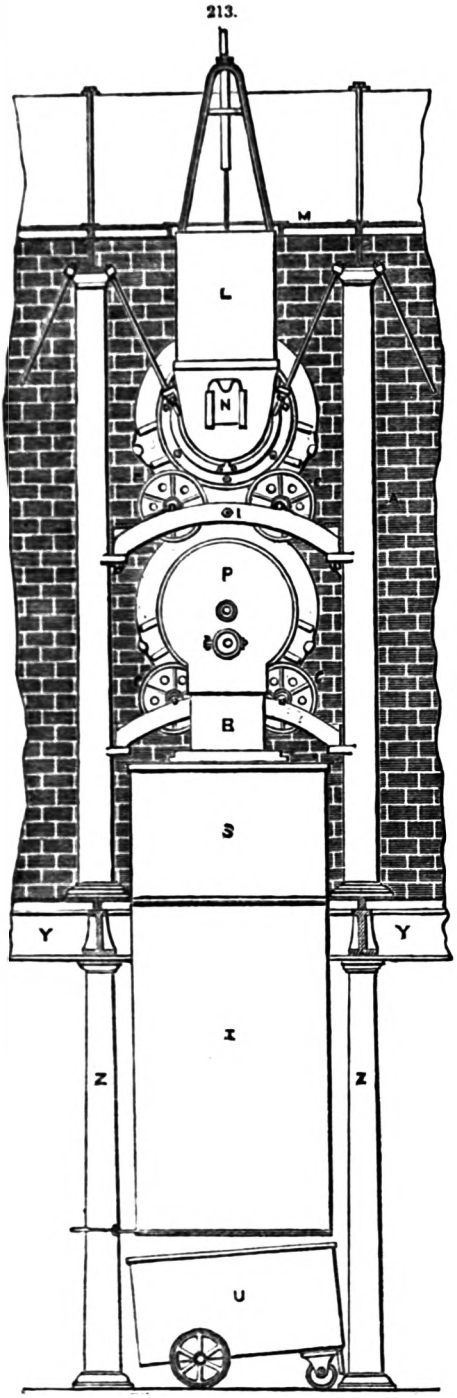
$6\sqrt{\frac{1}{4}} = 18$. Work in the stone $= \frac{18 \times 386}{64\frac{1}{2}} = 108$. Let $x$ be the number of revolutions, then $\frac{8}{12} \times \frac{386}{7} \times x =$ the work destroyed in $x$ revolutions. *Byrne's Essential Elements of Practical Mechanics.*

ANIMAL CHARCOAL, MACHINERY FOR REBURNING.

ANIMAL-CHARCOAL MACHINE. FR., *Machine à purifier le noir animal*; GER., *Maschine zur Bereitung der Thierkohle*; ITAL., *Macchina da carbone animale*; SPAN., *Máquina para purificar el carbon animal.*

The apparatus of J. F. Brinjes, of London, for reburning animal charcoal is shown in Figs. 213, 214, 215, 216.

213.




215.

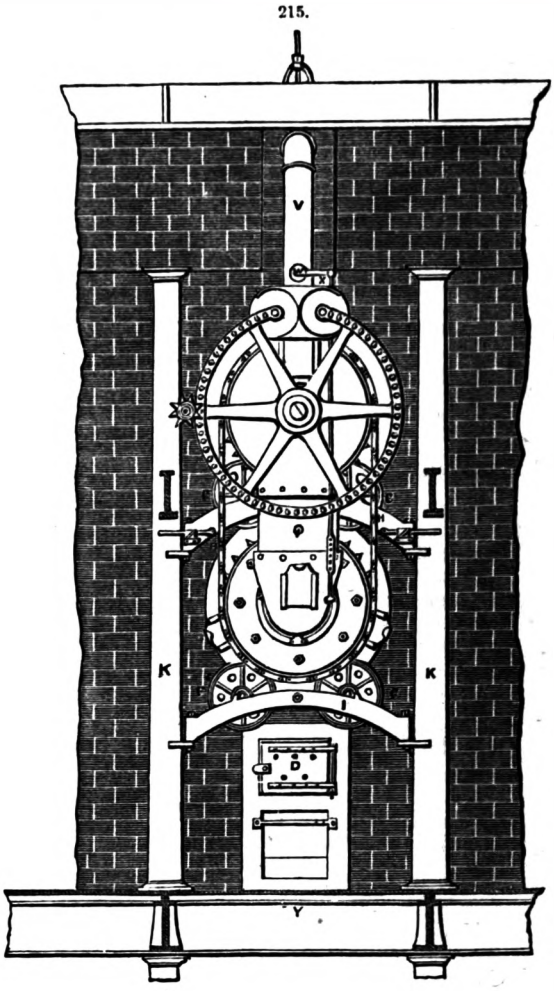


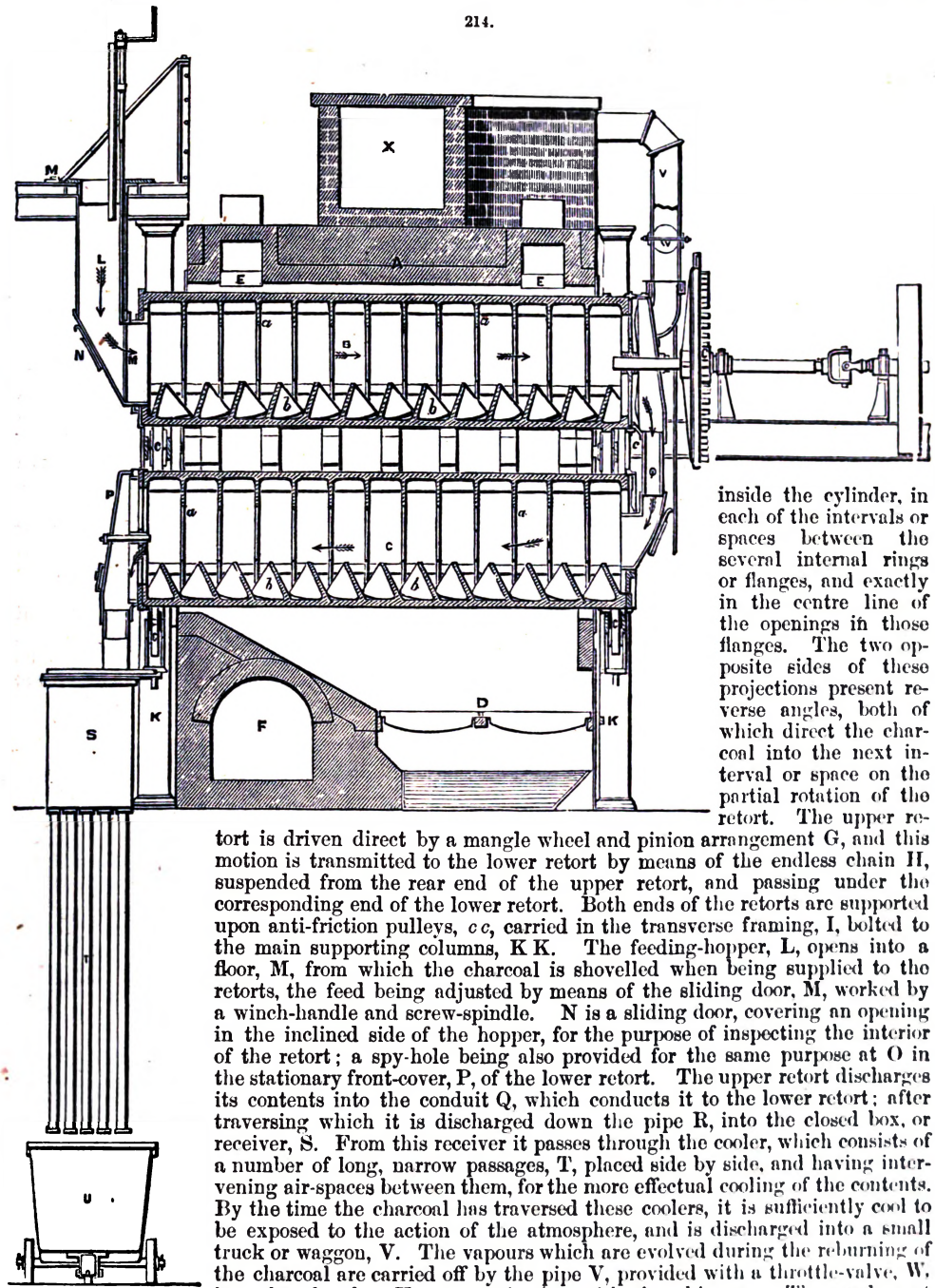

Fig. 213 represents a front elevation of the apparatus. Fig. 214 is a sectional elevation of Fig. 213.

Fig. 215 is a back elevation, and Fig. 216 is a section at the back of the apparatus. A is the brick-setting of the horizontal retorts, B, and C, each of which receives a circular reciprocating motion of nearly one entire revolution on its longitudinal axis. The upper retort, which acts as a drying-chamber for preparing the charcoal for the re-carbonization which takes place in the lower retort, is contained in a separate brick-chamber of its own, which is situated immediately above the roof of the furnace or fireplace D, the heat from which, after circulating round the lower retort, enters the upper chamber through openings left for that purpose in the roof of the furnace, and then acts upon the upper retort before passing off to the chimney. E E are passages provided with dampers, and leading to the main flue, F, below. The two retorts are provided with a series of internal flanges, *a*, *a*, at intervals of about 6 or 8 inches, and ledges are formed between the flanges for carrying up the charcoal as the retorts

reciprocate. An opening is made through each flange, and all these openings are disposed in a line with each other.

In order to cause the charcoal to travel continuously along the retorts during the process of re-carbonizing, an angled projection, somewhat after the form of a three-sided pyramid, *b*, is cast

214.



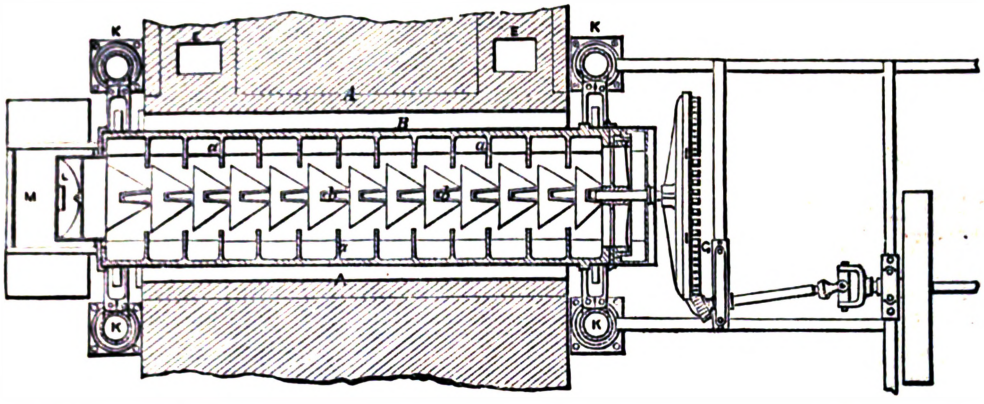

inside the cylinder, in each of the intervals or spaces between the several internal rings or flanges, and exactly in the centre line of the openings in those flanges. The two opposite sides of these projections present reverse angles, both of which direct the charcoal into the next interval or space on the partial rotation of the retort. The upper retort is driven direct by a mangle wheel and pinion arrangement G, and this motion is transmitted to the lower retort by means of the endless chain H, suspended from the rear end of the upper retort, and passing under the corresponding end of the lower retort. Both ends of the retorts are supported upon anti-friction pulleys, *c c*, carried in the transverse framing, I, bolted to the main supporting columns, K K. The feeding-hopper, L, opens into a floor, M, from which the charcoal is shovelled when being supplied to the retorts, the feed being adjusted by means of the sliding door, M, worked by a winch-handle and screw-spindle. N is a sliding door, covering an opening in the inclined side of the hopper, for the purpose of inspecting the interior of the retort; a spy-hole being also provided for the same purpose at O in the stationary front-cover, P, of the lower retort. The upper retort discharges its contents into the conduit Q, which conducts it to the lower retort; after traversing which it is discharged down the pipe R, into the closed box, or receiver, S. From this receiver it passes through the cooler, which consists of a number of long, narrow passages, T, placed side by side, and having intervening air-spaces between them, for the more effectual cooling of the contents. By the time the charcoal has traversed these coolers, it is sufficiently cool to be exposed to the action of the atmosphere, and is discharged into a small truck or waggon, V. The vapours which are evolved during the reburning of the charcoal are carried off by the pipe V, provided with a throttle-valve, W, into the chamber X, communicating with the chimney. The unpleasant consequences arising from the free escape of noxious effluvia are thus obviated. The entire arrangement is supported upon strong iron girders, Y, resting upon columns, Z, in the basement.

Each apparatus of two cylinders over one furnace is capable, in ordinary working, of reburning about 90 tons of animal charcoal a-week, with a consumption of about 10 tons of coal, or at the rate of only 1 ton of fuel to 9 tons of charcoal.

Animal charcoal is prepared by calcining bones. The bones are either placed in closed retorts, similar to those employed in the manufacture of gas for illuminating purposes, or, better still, in closed iron or earthenware pots, piled one above another in kilns, somewhat similar to pottery-kilns. Each pot contains about 50 lbs. weight of bones; and the time required for the complete calcination of a charge is from fourteen to eighteen hours. The pots, after they are withdrawn from

the kiln, are kept closed for a time, in order to exclude the air; and when sufficiently cool, their contents are discharged into a magazine. The calcined bones, in the state of animal charcoal, are

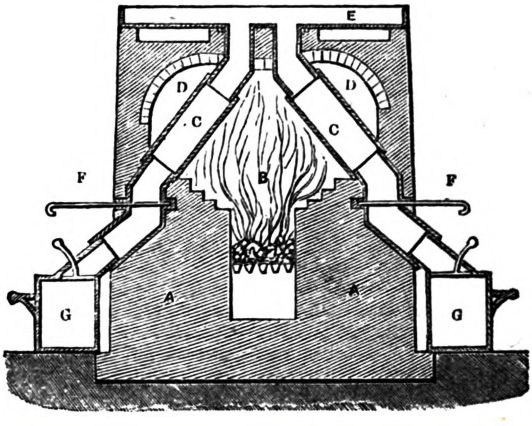
216.




subsequently crushed by passing them through rollers, which are grooved in order to prevent the formation of dust or fine powder; the charcoal being required in a granulated state, and free from dust, for the purposes of the sugar-refiner. After being used some little time in the clarifying of sugar, the charcoal loses its decolourizing properties; and, in order to restore them, it is subjected to a revivifying process, which consists in first thoroughly washing it, for the purpose of removing the saccharine matter adhering to it, and then allowing it to dry. When dry, it is placed in close vessels, or retorts, and recalcined. On cooling, it is found to have almost entirely regained its former virtue. The immense consumption of animal charcoal in the purifying or decolourizing of sugar, about 70 tons of charcoal to 100 tons of sugar, renders the process of revivifying one of considerable commercial importance.

In France, the reburning or revivifying of animal charcoal has long been carried on, but until very recently in a crude and imperfect manner, compared with the mechanical appliances which have been for some years brought to bear upon this branch of industry in this country. The arrangement designed by Crespel-Delisse, of Arras, is shown in Fig. 217, which represents a transverse vertical section of the furnace, taken through two of a series of twenty retorts, placed side by side in pairs, and heated by one furnace. A is a brick-setting, and B the furnace, above and on either side of which are arranged the inclined retorts, C C, set in the combustion-chamber D. These retorts are of a rectangular section, and open at their upper ends on to the plate E, upon which the animal charcoal is spread for the purpose of drying it before it is shovelled into the retorts. Near the bottom of each retort is fitted a sliding door, F, which is kept shut whilst the reburning is going on, and opened to empty the retorts. The charcoal, as soon as the discharging-doors are opened, descends by its own gravity into closed receivers, G, where it is kept from contact with the atmosphere until sufficiently cool to be packed.

217.



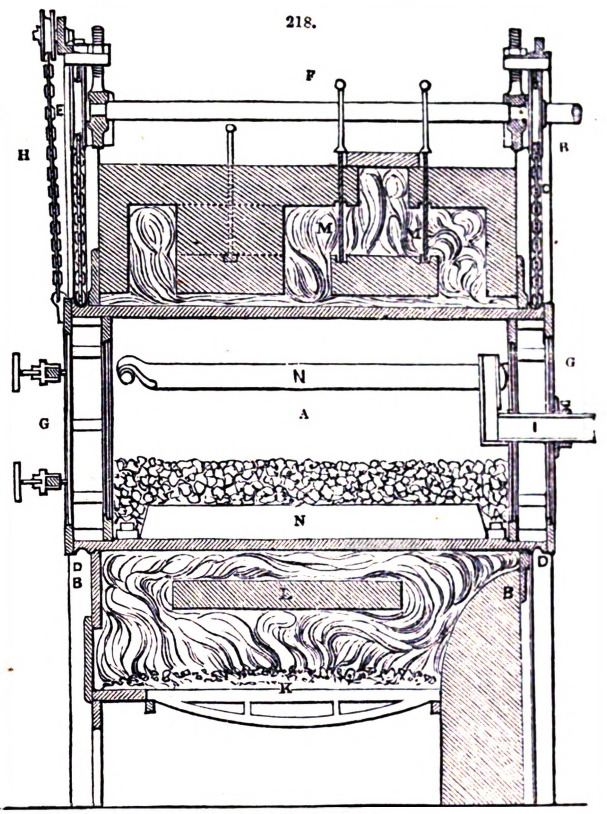

Each receiver is capable of containing one charge of the retort; and by the time the charge has sufficiently cooled, the succeeding one which has been introduced into the retort will be ready for discharging, consequently the process is almost continuous. From twenty-five to fifty minutes are required for the reburning of each full charge of the entire series of twenty retorts, which, working day and night, give on an average about one ton of animal charcoal in the twenty-four hours. The consumption of fuel is at the rate of about one ton of coal for five tons of revivified animal charcoal.

When crucibles or pots are used, the gas evolved through openings left for that purpose readily ignites, and so assists in the burning of the charcoal; the result being a probable saving of fuel, as compared with the consumption when ordinary closed retorts, similar to gas-retorts, are employed.

The first improvement of any note in the appliances for reburning animal charcoal was effected in 1846 by J. W. Bowman, who introduced revolving retorts in lieu of stationary apparatus, whereby the charcoal, by being constantly agitated and turned over during the process of reburning, is more readily and uniformly operated upon, thus effecting a saving of both time and fuel. Fig. 218 shows a longitudinal vertical section of Bowman's arrangement. A is a cylindrical horizontal retort, which revolves in bearings formed in the two fixed end-plates B, rotatory motion being given to the retort by means of endless chains, C, passing round large grooved pulleys, D, on each end of

the retort, and over corresponding pulleys, E, on an overhead shaft, F, driven by steam or other power. Each extremity of the retort is provided with a door or cover, G, the front one of which is so fixed as to be readily removed, and when removed, suspended by the chain, H, which passes over overhead guide-pulleys, and has a counter-weight suspended thereto. I is a tube in the back-cover, through which any vapours driven off from the animal charcoal may pass away to a condenser. K is the fireplace or furnace for heating the retort; and to prevent it acting too violently on the retort, fire-bricks or lumps, L, with openings in them, are interposed between the fire and the retort. M M are dampers for regulating the fire. Inside the retort are fitted a number of ledges, N, which, during the revolution of the cylinder, cause the animal charcoal to be deflected towards the centre, thereby effectually burning and regulating the contents whilst subjected to the action of the fire. The flames and products of combustion have free play round the sides of the retort; and as the latter is constantly revolving, it becomes uniformly heated. In using this apparatus, a charge of animal charcoal is introduced through the front door, which is then closed, and the retort set in motion till the charge is properly reburnt, after which it is withdrawn and a fresh charge introduced, the process being intermittent.

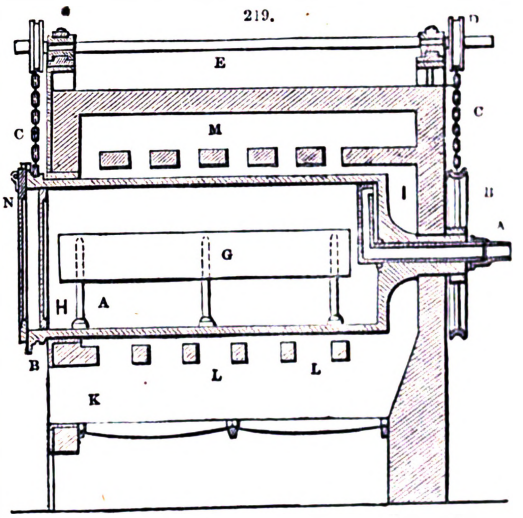
218.




The improvements in the construction and setting of revolving retorts for reburning animal charcoal, introduced in 1832 by George Torr, are shown in Fig. 219. The sides and one end of the retort are contained within the combustion-chamber; thus the end of the retort is heated by the flames which are allowed to play round it.

Fig. 219 is a longitudinal vertical section of Torr's apparatus. The retort A is cylindrical, and revolves on a horizontal axis. That end of the retort situated inside the setting has a boss formed upon it, which passes out through the setting, and carries a large grooved pulley, B; a corresponding pulley being fitted on to the front end of the retort. From these two pulleys, endless chains, C, pass over corresponding pulleys, D, on the shaft, E, by means of which a continuous rotatory motion is transmitted to the retort. F is a pipe for carrying off the vapours, and G is a long plate fixed by arms, H, to the interior of the retort, for the purpose of turning over its contents. The addition of this plate alone makes a difference of nearly ten tons of charcoal in favour of Torr's arrangement as compared with Bowman's. I is the combustion-chamber, within which the retort revolves, and which is separated from the furnace, K, by the fire-clay lumps, L. Openings in the roof of the chamber afford a communication with the flue, M, leading to the chimney. The charging and emptying door is hinged to the retort at N. This process is also intermittent, as the retort is stopped whilst being filled and emptied.

219.



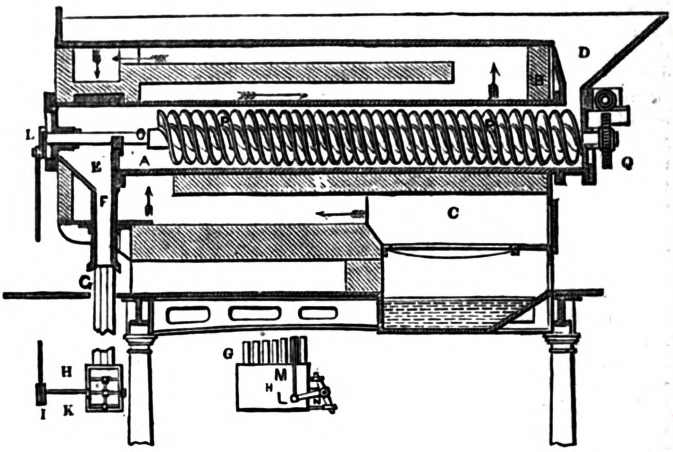

In 1856, James Bryant obtained a patent for the use of retorts having a reciprocating or alternating rotatory motion on their axes, in lieu of a continuous rotatory motion, as in Bowman and Torr's arrangements. Bryant's retorts were constructed and arranged in a similar manner to Torr's, with a space between their inner ends and the setting for the free circulation of the flame and gases from the furnace below. They were suspended at one or both ends by endless chains

passing over pulleys on a driving-shaft above, which shaft received an alternating or reciprocating rotatory motion by means of the "mangle wheel" or pinion arrangement, and consequently the retorts were made to reciprocate on their axes. The interior of each of the retorts was provided with ledges similar to Bowman's, for the purpose of turning over and deflecting the charcoal towards the centre of the cylinder. According to Bryant's mode of setting, a number of retorts were ranged side by side, and their several actuating shafts were geared together, so as to work in concert, the first shaft of the series only being driven by the reversing arrangement.

The first arrangement rendering the process of reburning animal charcoal continuous was invented by Brinjes and Collins in 1858; the retorts, according to their system, being continuously charged at one end and emptied at the opposite end by the aid of an *Archimedian screw* inside the retort.

Fig. 220 represents a longitudinal vertical section of a portion of Brinjes and Collins' arrangement. The retort consists of a longitudinal cylinder, A, which does not revolve, but is set permanently in the brick-work, B, in such a manner as to leave a free space all round it for the circulation of the flames and gases from the furnace, C, beneath. Into one end of the retort opens the mouth of a feeding-hopper, B, whilst its opposite end opens direct into a chamber, E, which leads by the passage, F, into a number of narrow cooling-tubes, G, in passing down which the charcoal is sufficiently cooled to be ready for packing. These tubes open at their lower extremities into a box, H, shown also in side-elevation detached, fitted with two slides, in the form of gratings, which slide over other gratings fixed inside the box. These slides are moved by the double lever, I, on the spindle, K, which spindle receives a rocking motion from a crank-pin, L, through the intervention of the rod, M, and lever-arm, N. The crank-pin is carried on the end of the shaft, O, of an *Archimedian screw*, P, revolving slowly inside the retort A, in order to move the charcoal steadily along whilst being reburnt, and to discharge it into the chamber, E, and cooling-tubes, G. The screw derives its rotatory motion from a worm gearing into a worm-wheel, Q, on the screw-shaft; this shaft, which carries the worm, being driven by a belt and pulley. It will thus be seen that the apparatus is self-discharging; for at every revolution of the crank, L, the slides in the discharging-box will be alternately opened and closed, so as to allow a small quantity of the charcoal to fall through the lower grating into a receptacle. A pipe is connected with the chamber, E, for carrying off the vapours and gases evolved from the charcoal inside the retort, and conveying them to a condensing-worm or other condensing-apparatus.

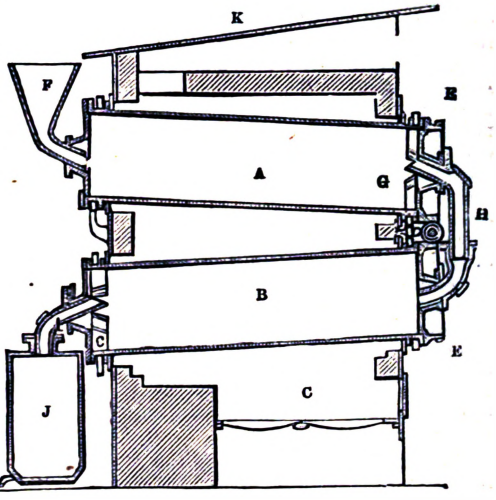
220.




The idea of a continuous process of charging and emptying the retorts, first carried out by Brinjes and Collins, was subsequently followed up by Drummond, of Montreal, and a patent was obtained in this country for his arrangement, in the name of James Paterson, in the year 1862.

Drummond's plan, Fig. 221, consisted in placing two or more inclined revolving or reciprocating retorts at reverse angles one above another, so that the charcoal descends by its own gravity from the upper to the lower retort of the series. The figure represents a longitudinal vertical section of this arrangement. A and B are two cylindrical retorts, inclined in reverse directions, and placed one above the other. The flame from the furnace, C, has free play round the sides of both retorts, which are caused either to revolve continuously, or to have an alternating motion on their axes, by means of a worm, O, gearing simultaneously into two worm-wheels, E, fitted on to the end of the upper and lower retort respectively. The upper retort, A, is supplied with charcoal by the feeding-hopper, F, and as it revolves, its contents caused to descend gradually along the interior, until it reaches the lower end, where it is lifted up by a series of vanes, G, attached to the end-cover of the retort, and by them discharged into a pipe, H, leading to the higher end of the retort below. After

221.

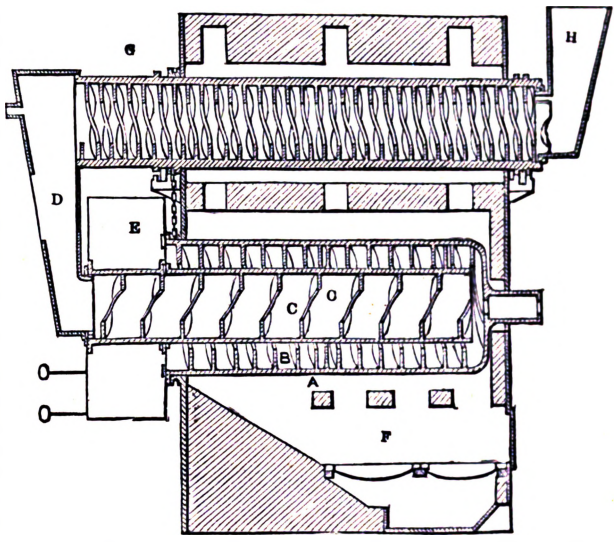


traversing the second retort, the charcoal is again lifted up by a set of revolving vanes, G, and discharged into the pipe, I, which conducts it to the closed vessel or receiver, J, where it remains until cool enough to be packed. By employing two or more retorts in connection with each other, and so arranging them that the last, or that in which the operation is completed, shall receive the greatest heat, whilst the first of the series, or that into which the charcoal is first supplied, receives the least amount of heat, a considerable saving of fuel is effected, as the otherwise waste heat, after having acted upon the lower retort, serves to heat the upper one, and thereby to gradually prepare the charcoal for the greater heat of the finishing retort. K is the upper surface or top plate of the *kiln* upon which the charcoal may be dried and then shovelled into the feeding-hopper, the plate being slightly inclined to facilitate this operation. Drummond, it appears, was the first to propose the use of two or more retorts placed one above another.

In 1862, Torr obtained another patent for apparatus for manufacturing and reburning animal charcoal, whereby the process is carried on continuously, instead of intermittently, as in his first arrangement.

Fig. 222 is a longitudinal vertical section of this subsequent arrangement. A is a revolving retort, placed horizontally, and provided with an *Archimedian screw*, B, in the interior thereof. In the interior of this cylinder, termed the "main cylinder," there is placed another and smaller cylinder, C, the axis of which coincides with the axis of the main cylinder, a space of about 1 inch being left between the exterior of the inner cylinder and the threads of the screw, B. This inner cylinder is open at both ends, and extends to within 6 or 8 inches of the back end of the main cylinder, and projects about 2 feet beyond the front of it. It is secured to the outer cylinder, and revolves with it.

222.

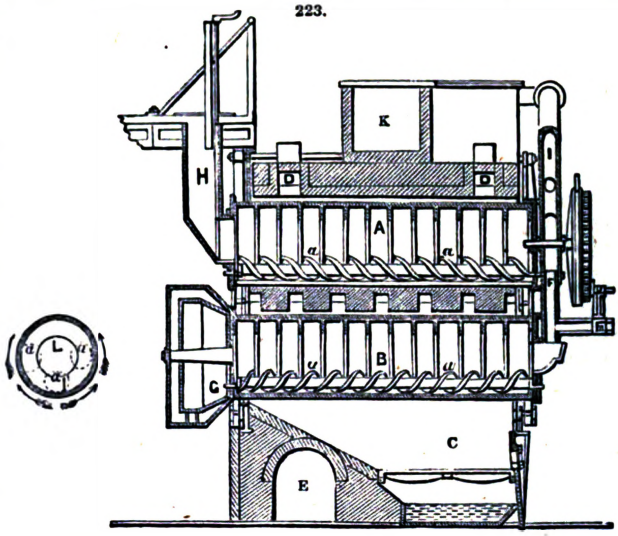



An *Archimedian screw* is also formed inside the inner cylinder, but in the reverse direction to that of the main cylinder; and its pitch and depth must be in accordance with the different diameters and pitch of the outer screw, so that the crushed bones or charcoal will travel with the same velocity and in a continuous stream through each cylinder. At the front end of the inner cylinder there is a stationary hopper, D, for supplying the bones or charcoal; and to the front ends of the cylinders, A and C, is secured a revolving cooling-box, E, consisting of a double drum of sheet iron, the inner drum having about the same diameter as the interior of the main cylinder. The outer side or face of this drum is closed; but the inner side, next to the main cylinder, is left open in the centre to receive the contents of the cylinder, A, after being operated upon. A slide is placed between the inner and outer drum, for the purpose of discharging the contents from the inner into the outer drum, where they are kept from contact with the atmosphere till sufficiently cooled to be discharged from the outer drum, by opening another sliding door. In order to economize fuel, the waste heat from the furnace, F, after passing round the outer or main cylinder, A, and before passing to the chimney, enters a brick chamber in which there is a revolving cylinder, G, by preference of the same diameter as the inner cylinder, C, and provided with an internal *Archimedian screw* attached to or cast on its inner surface. The crushed bones or charcoal are fed into the upper cylinder from the stationary hopper, H; and, after traversing the length of the cylinder, are discharged down the shoot and hopper, D, which direct them into the inner cylinder, C. After traversing this cylinder in one direction, the charcoal is discharged at the inner end of the cylinder into the main or outer cylinder, and returns in the contrary direction, being finally discharged into the revolving cooling-box.

In 1864, J. F. Brinjes contrived an arrangement of horizontal cylindrical retorts, having a circular reciprocating, instead of a continuous rotatory, motion on their axes. Fig. 223 represents a sectional elevation of this arrangement. A and B are the upper and lower retorts; the upper one receiving a circular reciprocating motion direct from a mangle wheel and pinion, or other convenient contrivance; and the lower one deriving a similar motion from the upper one by means of an endless chain passing over the end of the upper retort, and under the end of the lower one, suitable teeth or projections being furnished for taking into the links of the chain. These retorts are contained in separate chambers above the furnace or fireplace, C, openings being made in the roof of the lower chamber communicating with the upper one, so that a free circulation of the heat from the furnace is allowed to take place around both retorts before it escapes by the passages, D D, leading to the flue, E, and chimney. In the interior of each retort a number of internal flanges are fixed at regular intervals, and an opening is made in each flange of the series, such openings being in a line with each other, from end to end of the retorts—the arrangement so far being the same as that shown in Fig. 223. Along this line of openings a rocking cranked shaft passes, which carries a number of inclined vanes or plates, *a*, one in each of the

intervals between the flanges. As the cylinders reciprocate round their axes, the cranked shafts, with their vanes, turn over, partly by their own gravity, so as to reverse the angle of the vanes; and consequently the charcoal, as it falls down the rising side of the retort, will come in contact with the vanes, and by that means be deflected into the adjoining interval. When the retort reverses its motion, the vanes turn over to the opposite angle, and the charcoal is again directed by the inclined surfaces into the next one of the intervals between the flanges, and so on till it has travelled from end to end of the retort. I. is a transverse section of one of the retorts, showing the different positions of their vanes or deflectors. The charcoal is discharged from the end of the upper retort into a pipe, F, which conducts it into the end of the lower retort, through which it travels as above described, and is finally discharged into a double revolving cooling-box, G, which is kept cool by a water-jacket. The feeding-hopper is shown at H. It opens out to a floor or platform above the retorts, whereby the charcoal can be readily shovelled into it, and is provided with a sliding door for regulating the feed. I is a pipe communicating with the connecting-pipe, F, of the retorts, for the purpose of carrying off the vapour and effluvia evolved from the charcoal and conveying it into the chamber, K, leading to the chimney, a throttle-valve in this pipe serving to regulate the draught to the extent required.

223.




ANNEALING-FURNACE. Fr., *Fourneau à recuire*; Ger., *Kühlofen, Auswänneofen*; Ital., *Forno da ricuocere*; Span., *Horno para templar vidrio.*

See Furnaces.

ANNULAR PISTON. Fr., *Piston annulaire*; Ger., *Ringförmiger Kolben*; Ital., *Stantuffo anulare*; Span., *Embolo anular.*

See Details of Engines. Pumps.

ANTI-CORROSION. Fr., *Anti-corrosion*; Ger., *Gegen-Aetzung*; Ital., *Anticorrosivo*; Span., *Anti-corrosion.*

See Corrosion.

ANTI-FRICTION METAL. Fr., *Métal pour diminuer le frottement*; Ger., *Reibung verminderungs Metal*; Ital., *Lega di antifregamento*; Span., *Metal para disminuir el rozamiento.*

Babbit's metal is usually termed *Anti-friction metal*; it is composed of 50 parts tin, 5 antimony, and 1 copper. See Alloys. An alloy of tin and pewter is often used as an anti-friction metal for the bearings of engines.

Fenton's anti-friction metal is a mixture of tin, copper, and zinc; it is lighter than gun-metal, and of a soapy character, so that less oil or grease is required with it than with gun-metal.

The anti-friction metal in use on some of the Belgian railways is, in places exposed to much friction, composed of 20 parts copper, 4 tin, 0·5 antimony, 0·25 lead; and for parts subjected to great concussions, 20 copper, 6 zinc, 1 tin; for surfaces exposed to heat, 17 copper, 1 zinc, 0·5 tin, 0·25 lead. Mix the last-mentioned ingredients, and then add the copper.

For the bearings of axles and journals, a compound grease is often employed, and termed anti-friction grease. P. S. Develin oil, which is composed of hog's-lard and gutta-percha, when mixed with black-lead is termed anti-friction oil, and frequently used in the United States.

At Munich a composition is used consisting of 10·5 parts hog's-lard, melted with 2 of finely-powdered and sifted black-lead. The first of these ingredients is gently melted, and when liquid the black-lead is gradually added, the whole being stirred until the ingredients are thoroughly incorporated, and until the mixture is quite cool.

ANTIMONY. Fr., *Antimoine*; Ger., *Antimonium, Spieszglanz*; Ital., *Antimonio*; Sp., *Antimonio.*

The properties of *antimony* are in many respects distinguished from those of other metals, particularly in its tendency to crystallize. When antimony is melted in a pot and suffered to cool on its surface, and the fluid part then cast off, a mass of beautiful crystals remains in the pot. Antimony is very brittle. It may be pulverized in a mortar. It is silver-white, and with a brilliant lustre. It fuses at about 800°, or at a dull red heat, and volatile at white heat. Its specific gravity is 6·7. The metal in its pure condition is not in use, but alloyed with other metals is much employed. The only useful ore of antimony is its sulphuret; no other kind is obtained in sufficient quantity to be smelted.

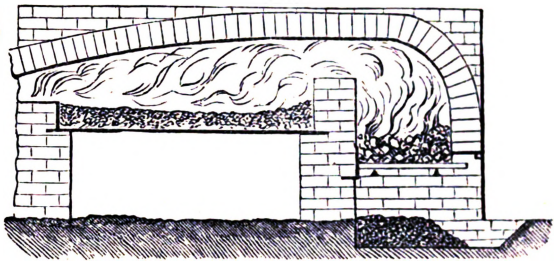
The sulphuret of antimony occurs in masses, consisting of crystalline needles, which are closely united. It is of metallic lustre, of a grey colour, and forms a grey powder. When gently heated, it turns black, or is iridescent. It is extremely fusible, and melts in the flame of a candle with the exhalation of a sulphureous smell. After being heated, the powder is very black. This ore consists of 72·86 metal and 27·14 sulphur. Its specific gravity is 4·1 to 4·6. Sulphuret of antimony occurs in and near the veins of sparry iron-ore, with heavy spar, blende, galena, quartz, and other minerals. Most of the metal in market is obtained from Germany.

*Alloys.*—All the antimony metal of commerce may be considered an alloy. It is never pure, but contains iron in all instances. Antimony and tin, melted together in equal parts, form a moderately hard, brittle, but very brilliant alloy, which is not soon tarnished, and is frequently employed for small speculums in telescopes. Of all the metals, antimony combines most readily with potassium or sodium. These alloys are obtained by smelting the carbonaceous compounds of these metals, or their oxides mixed with carbon. The presence of other metals, such as copper or silver, does not diminish the affinity of these metals for antimony. The alloy thus formed of the alkaline metals and antimony is not easily evaporated by a strong heat. Arsenic and antimony combine in all proportions, and form, unexpectedly, a tenacious alloy, which is very fusible, compact, and often of a granular texture. It has been remarked, in speaking of the alloys of iron, that this metal alloyed with iron causes the compound to be extremely hard. Eighty parts of lead and 20 of antimony form type-metal; to this commonly 5 or 6 parts of bismuth are added. Tin 80 parts, antimony 20, is music-metal; it is also composed of 62·8 tin, 8 antimony, 26 copper, and 3·2 iron. Plate-pewter also contains from 5 to 7 per cent. of antimony; 89 tin, 7 antimony, 2 copper, 2 iron, is one of these compositions. Britannia-metal contains frequently an equal amount of antimony. Queen's-metal is 75 tin, 8 antimony, 8 bismuth, and 9 lead.

*Uses of Antimony.*— Besides its employment in medicine, it is much used for forming alloys; of these, type-metal and anti-friction metal—which is type-metal with the addition of copper—are those most used. Crude antimony is employed for purifying gold.

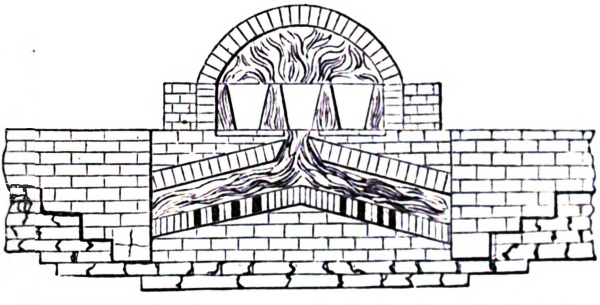
*Manufacture.*—The smelting of this metal is very simple. It is easily revived from its ore, which, however, is attended with a heavy loss of metal. The crude ore is picked by hand; the pieces are broken to the size of an egg; and, by means of a hand-hammer, the gangue, such as quartz, barytas, or carbonate of lime, is removed. These pieces may be heated in an earthenware pot, in the bottom of which there is a small aperture. The sulphuret of this metal, melting at a very low heat, will flow out from the gangue, and may be gathered in another pot set below. The operation used to be performed in this manner; but, as it is expensive, the ore is at present melted in a reverberatory furnace, similar to that shown in Fig. 224, the hearth of which is very concave, and formed of sand. In the centre of the hearth, at its deepest part, there is a tap-hole which communicates with one of the long sides of the furnace. The ore, on being sorted, is spread over the hearth of the furnace, and is there melted. The tap-hole is stopped by dense coal-dust while the reduction is going on. About three-hundredweight of ore is charged at once, mixed with iron-ore or hammer-slag, and heated, with an occasional stirring. Eight or ten hours are sufficient to finish one heat, after which the metal is tapped, the scoria removed, and the furnace charged anew.

224.



The metal thus obtained is not pure. It contains iron, sulphur, arsenic, lead, and copper; from most of these admixtures it may be freed to a certain extent, but not entirely. This metal is refined by remelting it in crucibles, arranged on the hearth of a reverberatory furnace similar to the one shown in Fig. 225. The pots contain about 30 lbs. of metal, which is covered with coal-dust. These are exposed to a low, uniform heat for some hours. Most of the metals are thus oxidized, and may be removed after emptying the crucibles.

225.



The smelting operation is in some instances divided into two manipulations; the one, or first, is a process of liquefaction, in which the crude antimony is melted in vertical pipes, and thus separated from the gangue, which remains in the retort while the former filtrates through the perforated bottom.

In this operation much of the antimony is lost. A part of it adheres to the gangue, which in pool amounts to 25 per cent., and is never less than 10 per cent. Part of the crude antimony also volatilizes, which increases the loss. This loss is, therefore, an important object where the ore is expensive; and it may be in most cases the best plan to stamp and wash it while crude, free from the rocky matter, and then subject it to reduction by direct smelting. The specific gravity of the ore is sufficiently great to remove the most of the gangue. Metallic sulphurets of other metals than antimony, of course, remain with it. The crude antimony, or the concentrated ore-sand, is smelted with metallic iron, or iron-ore; and since it is difficult to add just as much iron as is required to absorb all the sulphur, and as too much imparts iron to the metal, the practice is to add either carbonate or sulphate of potash, or soda, and also fine charcoal-powder, to the ore. One part of metallic iron to 2 or 2·5 parts of crude antimony, ought to absorb all the sulphur; but when no other flux is present, about 20 per cent. of antimony remains in the slags. By using 42 parts of iron to 100 of crude antimony, with 50 carbonate of soda and 5 charcoal, nearly the whole of the antimony is revived. Instead of metallic iron, any kind of pure iron-ore may be

employed with more charcoal; but its metallic contents should come near the above-named quantity.

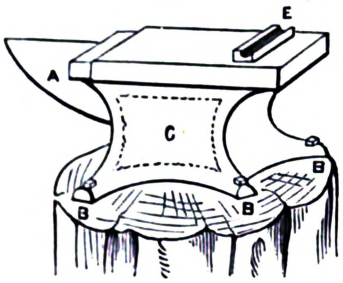
In refining the crude metal of antimony in crucibles, it is advantageous to soak the charcoal-powder with which the metal is covered, in a strong solution of carbonate of soda. When the metal is not sufficiently pure after the first refining, the operation is repeated. In all the operations with antimony, a high heat must be avoided, for the metal as well as the sulphuret is very volatile.

A fusible slag increases the yield of the ore.

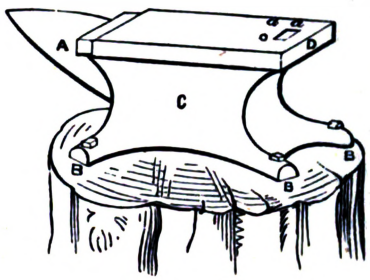
ANVIL. Fr., *Enclume;* Ger., *Amboss;* Ital., *Tuendine;* Span., *Yunque, Bigornia.*

An anvil is an iron block, usually with a steel face, upon which metals are hammered and shaped. The ordinary smith's anvil, Figs. 226, 227, is one solid mass of metal,—iron in different

226.




227.




states; C is the core or body; B, B, B, four corners for enlarging the base; D, Fig. 227, the projecting end; it contains one or two holes for the reception of set chisels in cutting pieces of iron, or for the reception of a shaper, as shown at E, Fig. 226. In punching flat pieces of metal, in forming the heads of nails or bolts, and in numerous other cases, these holes *a, a*, of ordinary anvils, are not only useful but indispensable. A is the beak-horn, which is used for turning pieces of iron into a circular or curved form, welding hoops, and for other similar operations. In the smithery, the anvil is generally seated on the root-end of a beech or oak tree; the anvil and wooden block must be firmly connected, to render the blows of the hammer effective; and if the block be not firmly connected to the earth, the blows of the hammer will not tell. The best anvils, anvil-stakes, and planishing-hammers, are faced with double shear-steel. The steel-facings are shaped and laid on the core at a welding heat, and the anvil completed by being reheated and hammered. When the steel-facing is first applied, it is less heated than the core. But the proper hardening of the face of the anvil requires great skill; the face must be raised to a full red-heat, and placed under a descending column of water, so that the surface of the face may continue in contact with the successive supply of the quenching fluid, which at the face retains the same temperature, as it is rapidly supplied. The rapidity of the flow of water may be increased by giving a sufficient height to its descending column; it is important that the cooling stream should fall perpendicularly to the face which is being hardened. Heat may escape parallel to the face, but not in the direction of the falling water. The operator, during this hardening process, is protected from spray and smoke by a suitable cover; and by confining the falling water to a tube which must contain the required volume. When an anvil is to be used for planishing metals, it is polished with emery and crocus powders. The skilful manner in which Henry Walker, of Red Lion Street, Clerkenwell, combines and carries out these apparently simple operations, in making anvils and planishing-hammers for silversmiths and metal-workers, gives him the reputation he so well deserves;—to describe a process is one thing, but the execution requires practice as well as skill. See Fullers. Shapers. Steam-hammer. Upsetting-block.

APERTURE. Fr., *Ouverture;* Ger., *Offnung;* Ital., *Apertura;* Span., *Abertura.*

In building, the term aperture is usually applied to doorways, windows, and other openings through the walls: the sides of a rectangular aperture are named "*jambs;*" the upper part, the "*head;*" and the bottom part, the "*sill.*"

APPROACHES. Fr., *Approches;* Ger., *Zujanj, Laufgraben;* Ital., *Approcci;* Span., *Aproches, Ataques.*

Works thrown up by besiegers, to protect them in their advances towards a fortress, are termed *approaches.* See Fortification. This term is also applied to those parts of a road which are raised to suit the level of a bridge over a railway or canal.

APRON, in Shipbuilding. Fr., *Eperon, Contre étrave;* Ger., *Binnenvorsteven, Ueberlauf;* Span. *Abitana de proa, ó contraestrabe.*

The apron, also termed stomach-piece, is a strengthening compass-timber, which is bolted behind the lower part of the stem, and immediately above the foremost end of the keel.

APRON. Fr., *Radier;* Ger., *Platform, Schleussen bett;* Span., *Zampeado.*

In engineering structures an *apron* is a platform of wood, stone, or brick, placed at the base of the structure, to protect it from abrasion or heavy shocks. The platform which receives the water falling through the sluices of a lock-gate or embankment is called an apron; the planking or platform placed at the toe of a sea-wall, to protect its base from the scour occasioned by the returning wave, is also termed an apron.

An apron in carpentry is the horizontal piece of timber which takes the carriage-piece, or rough string, of a staircase; and also the ends of the joists which form the *half-space* or landings. It should be firmly wedged at both ends into the wall.

In plumbers' work, the apron is the lead sheeting or *flashing* dressed on to the slates in front of dormer-windows or skylights.

APRON-LINING. Fr., *Contre-étrave;* Ger, *Binnenvorsteven;* Ital., *Fascia;* Span., *Travesera para sostener los larqueros de uña escalera.*

*Apron-lining*, as this term implies, is a lining placed outside the apron. It is applied by the joiner to the piece of wrought boarding which covers the rough apron-piece of the staircase.

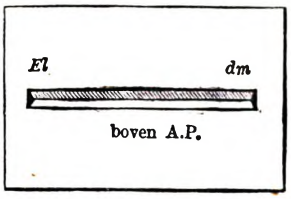
APRON-PIECE. Fr., *Contre-étrave*, Ger., *Binnenvorsteven.*

See Apron, *in Building.*

A. P. Fr., *Niveau d'Amsterdam;* Ger., *Amsterdammer Pegel.*

The letters A. P. are the initial letters of two Dutch words, Amsterdamsch Peil, meaning Amsterdam Level, and indicate the *Datum Line*, or mean level, from which all surveys are made in Holland, Belgium, and in the Northern parts of Germany.

223.

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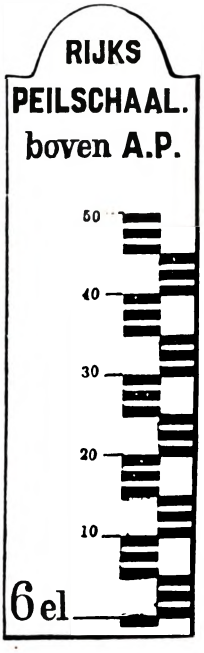



The A. P. is an imaginary plane, drawn through the average high-water mark of the North and Zuiderzeen Seas on the Dutch coasts, and derives its name from the circumstance of its having been adopted at Amsterdam from the year 1670.

It was carefully revised during the present century, under the direction of the Dutch Government; and in consequence of this careful revision, is the most accurately fixed sea-level.

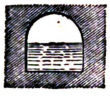
Figs. 228, 229, show the marks which are placed in various parts of Holland, to indicate the height above or below A. P. See Datum Line.

AQUEDUCT. Fr., *Aqueduc*, Ger., *Wasserleitung;* Ital., *Acquedotto;* Span., *Acueducto.*

A conductor, conduit, or artificial channel for conveying water, is termed an aqueduct.

*The Aqueduct of the Loch Katrine Waterworks.*—The description of this aqueduct is taken from a paper by James M. Gale, published in the 'Proceedings of the Institution of Mechanical Engineers, 1864.' The length of this aqueduct is about 34 miles. The built and tunnelled part of the aqueduct is 22 miles long, and 8 ft. high by 8 ft. broad; sections of it are shown in Figs. 230, 231, 232. It has an inclination of 1 in 6336, as shown in longitudinal section, Fig. 233, and is capable of passing fifty million cubic gallons a-day. The valleys of Duchray, Endrick, and Blane, *e f h*, Fig. 233, which are crossed by the line of aqueduct, and

230.



231.

232.

prevent a uniform inclination being obtained throughout, make up an aggregate length of 3¾ miles, and are passed by cast-iron siphon-pipes 48 inches in diameter, with a mean fall of 1 in 1000 between their extremities. These pipes deliver about twenty million gallons a-day, and provision was made for laying two additional lines of pipes, at bridges and other places where masonry was required, in order to increase the supply of water to the city when necessary. The first work upon the line of aqueduct, upon leaving Loch Katrine, is a tunnel through the ridge which separates the

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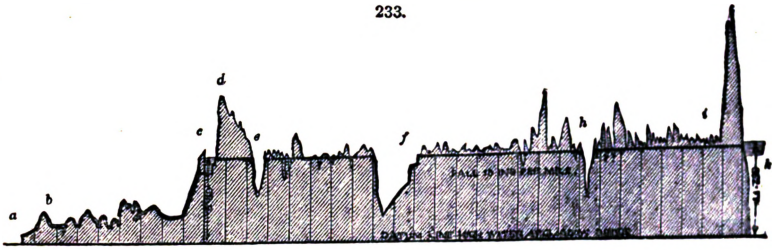
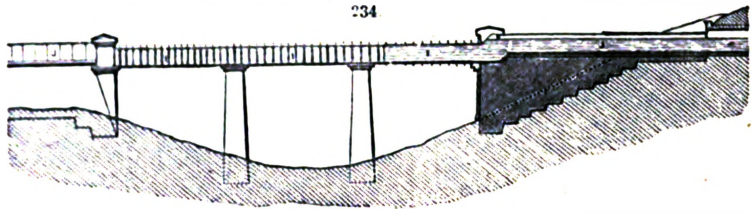



*Reference.*—*a*, River Clyde. *b*, Glasgow. *c*, Mugdock Reservoir and Straining-well. *d*, Mugdock Tunnel. *e*, Blane Valley. *f*, Endrick Valley. *g*, Drummore Tunnel. *h*, Duchray Valley. *i*, Loch Katrine Tunnel. *k*, Loch Katrine.

valley of Loch Katrine from that of Loch Ard. The length of the tunnel is upwards of 1·25 mile, and is at a depth of more than 500 feet below the top of the hill. Twelve shafts were sunk on the line of tunnel, to facilitate the work, five of them being about 450 feet deep. The rock passed through by this tunnel, and by the greater part of the first ten miles of the aqueduct, which is principally a series of tunnels, is mica slate, of the hardest description. Along the margin of Loch Chon, the work, at some of the faces, did not progress more than three lineal yards in a month, although it was

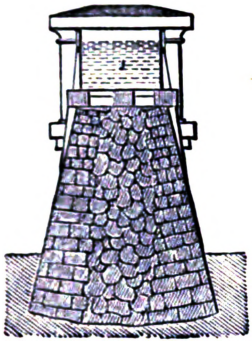
carried on night and day. The minor ravines in the first ten miles of the aqueduct are crossed by aqueduct-bridges of iron. Besides a number of smaller ones, there are five extensive aqueduct-bridges of this kind, one of which, near Culgarton, is shown in Figs. 234, 235, 236. It consists of a

234.



wrought-iron tube I, 8 ft. broad, and 6·5 ft. high inside, extending over the greater part of the ravines, supported at intervals of 50 ft. by stone piers; and a cast-iron trough, J, also 8 ft. broad, and 6·5 ft. high, supported on a dry stone-rubble embankment at either end of the wrought-iron tube I, extending over the remaining part of the valleys, where the ground is not much depressed. The bottom and sides of the wrought-iron tube I are $\frac{3}{8}$ in. thick, and the top $\frac{1}{4}$ in. thick, the whole being strengthened by angle and T iron. The plates of the cast-iron trough are $\frac{1}{2}$ in. thick, the dimensions of the largest being 4 5 ft. by 4 ft.; and they are connected and strengthened by flanges, with rust-joints. The level of the tube I is about 3 ft. lower than that of the cast-iron trough J J at each end, so as to ensure the tube being always completely filled with water, in order that the top of the tube may be kept at the same temperature as the sides, and that the tube may not be racked by the strain which would arise from the top plates becoming heated by the sun, if the water were not in contact with them. That the tube may be emptied at any time, for

235.



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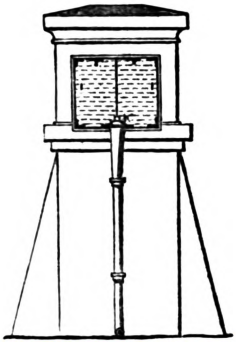

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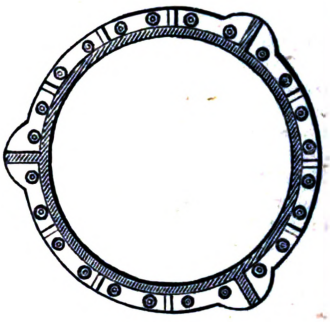
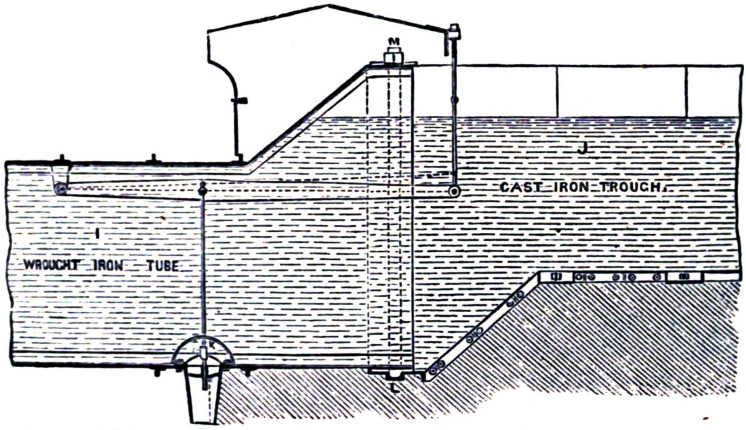


painting or other purposes, a discharge-valve, K, Figs. 236, 238, is provided at one end of the tube, by which the water can be run off into the valley beneath. The junction between the wrought-iron tube and the cast-iron trough is shown in Figs. 238, 239, and in detail in Figs. 240, 241. It is made by bolting the cast-iron trough to a cast-iron bed-plate, L, Figs. 237, 238, and to upright

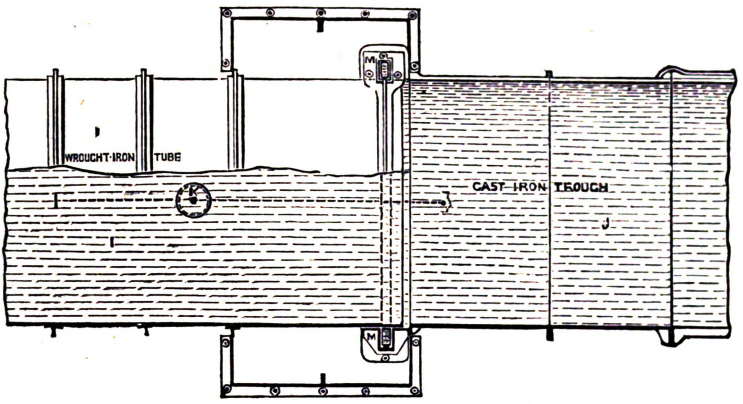
238.




cast-iron standards, M M, Figs. 239, 241, at each side. The wrought-iron tube rests upon a bolster of vulcanized india-rubber, placed in a groove in the bed-plate L, and projecting sufficiently above the surface of the plate to allow for the requisite compression on the india-rubber for making a water-tight joint by the weight of the tube bearing on it, without allowing the tube to come down to a bearing upon the bed-plate L itself. A similar india-rubber bolster is carried up each side of the tube, and compressed against it by oak wedges, the bolster and wedges being contained in a recess in the upright standards M M, as shown in Figs. 239, 241. This arrangement leaves the

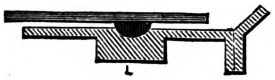
wrought-iron tube free to contract and expand longitudinally under change of temperature, without risk of leakage. The heads of all the rivets are countersunk for a short distance on each side of the bearing parts of the tube. The india-rubber bolsters are, both at the bottom and sides of the tube. 2 in. in diameter. They are in separate pieces; the bolster under the bottom extending

239.




from the wedge-box M on one side, to the back of the wedge-box on the opposite side. The joints of the bolsters at the bottom corners are made by butting the bottom ends of the vertical bolsters upon the top of the transverse bottom bolster, the bottom ends of the vertical bolsters being slightly rounded out to fit the curvature of the bottom bolster. The side wedges are driven down tight on

240.

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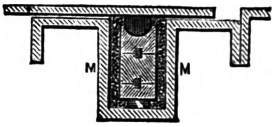
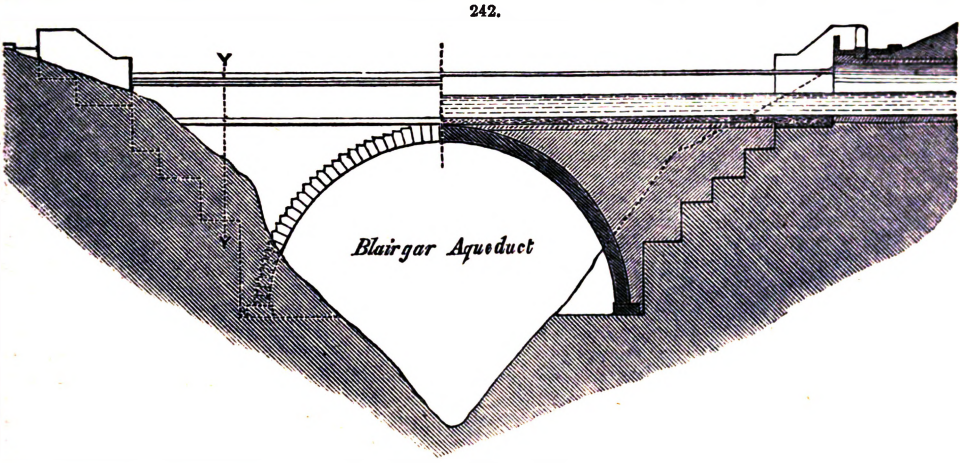



the ends of the bottom bolster. There are three oak wedges in each wedge-box, M, Fig. 241, with an oak feather, or tongue, let in to break the joints between the wedges, and to guide the centre wedge while being driven down. A flat strip of india-rubber, I, is placed between the back of the wedge-box and the outermost wedge. The wedges were carefully fitted before the feather-grooves

242.

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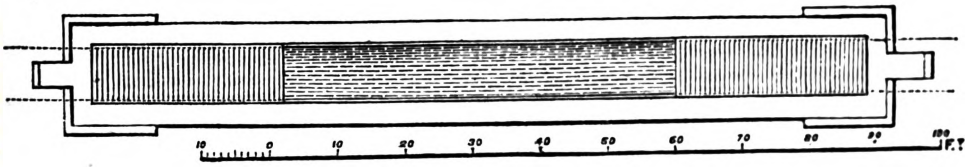
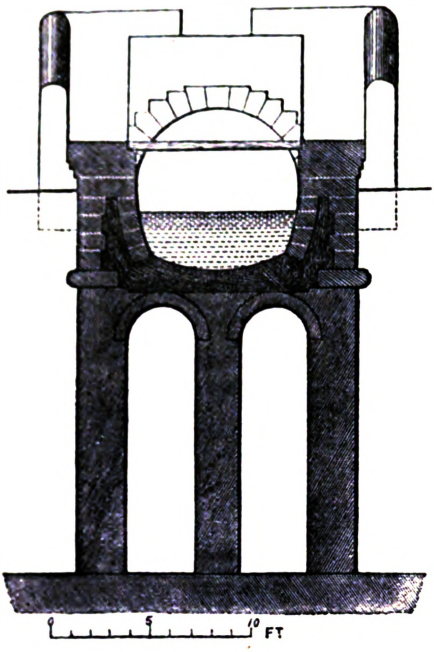



were made, and were put in with thick wet paint in the joints: the centre wedge was then driven down to tighten up the india-rubber bolster against the side of the tube, and the spaces on either side of the wedges in the standards M were filled with oakum and white-lead. The above construction

of the iron aqueduct-bridges was the most applicable in the first portion of the aqueduct, as no good building-stone could be obtained within reasonable distance, and the roads were badly suited for the carriage of materials. From the eleventh mile to the reservoir at Mugdock, however, good building-stone was abundant, and all the aqueduct-bridges in that district are therefore of stone. One of these is shown in Fig. 242, in elevation, and longitudinal section in plan, Fig. 243; and Figs. 244, 245, show transverse sections of the same. There are, in all, twenty-five important

244.

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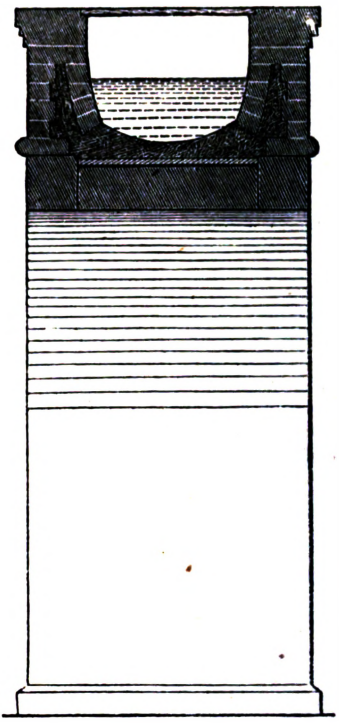

iron and stone bridges, some of them of considerable magnitude; and about eighty distinct tunnels, varying in length from 1½ mile downwards, and forming a total length of thirteen miles. Where the aqueduct was formed in open cutting, the ground was filled in and the surface restored, as shown in Fig. 232. At the cast-iron troughs of the iron aqueduct-bridges, and at the other bridges, the waterway is covered with planking, as shown in the sections of the Blairgar aqueduct-bridge, Figs. 244, 245, to prevent snow from choking the aqueduct. Grooves to receive stop-planks are cut in the masonry of the aqueduct at intervals, and most of the bridges are provided with overflow and discharge sluices. The latter are similar in construction to the outlet sluices of the locks, but of smaller dimensions. The three valleys of the Duchray, Endrick, and Blane, which are of great width and depth, the second being more than three miles wide, are passed by means of the 48-in. cast-iron siphon-pipes, carried down one side of the valley to the bottom, and up the opposite side. These pipes have the ordinary spigot and socket joints; a section of which is shown in Fig. 246, the joint being made with lead, N, and yarn, O. Some depressions on the line of these siphon-pipes are crossed by flanged pipes, supported upon stone piers, 18 ft. apart, as shown in Fig. 247, the joint being made by a ring of vulcanized india-rubber, P, as shown in section Fig 248. In the Endrick valley, two public roads, and the Forth and Clyde Railway, are crossed by these flanged pipes; and to support the pipes over these greater spans, cast-iron brackets are put in, abutting on the stone piers which are thickened to receive them. The pipes are further strengthened at these places by projecting webs cast on them, as shown by the enlarged transverse section of the pipe, Fig. 237. It was found that the expansion and contraction of these long lengths of flange-jointed pipes under changes of temperature injuriously affected the socket and spigot lead joints at each end; and to obviate this, a felt covering, about ¾ in. thick, was laid on all round the pipes, and protected from the weather by a tarpaulin cover, laced tightly over the whole. This has the effect of almost entirely obviating the inconvenience that arose from the expansion and contraction.

The service reservoir of Mugdock, Fig. 233, has a water-surface of 60 acres, and is 50 feet deep, the top water-level being 312 feet above the level of the sea. It contains 548,000,000 gallons when full, equal to a supply for twenty-nine days at the present rate of consumption; and thus admits of repairs being made upon the line of aqueduct without interrupting the supply to the city. The reservoir is entirely artificial, being formed by two earthen embankments, 400 yards and 240 yards long respectively. The water is first received from the aqueduct into a basin at the upper end of the reservoir, from which it flows over four cast-iron gauge-plates, 10 feet long each, brought to a thin edge, into an upper pool or compartment of the reservoir having an area of about 2 acres. The depth of water passing over the gauge-plates is regularly gauged, the delivery from

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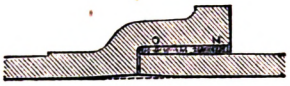

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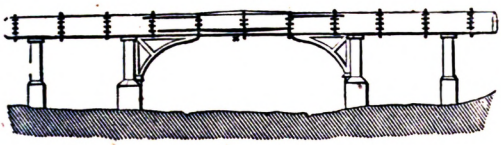

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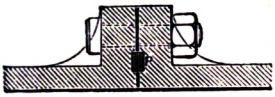

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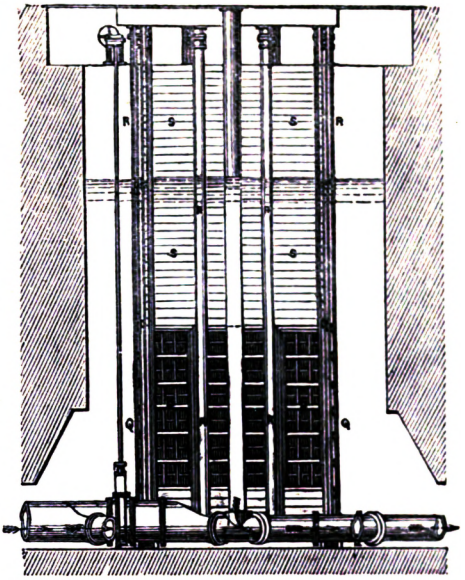

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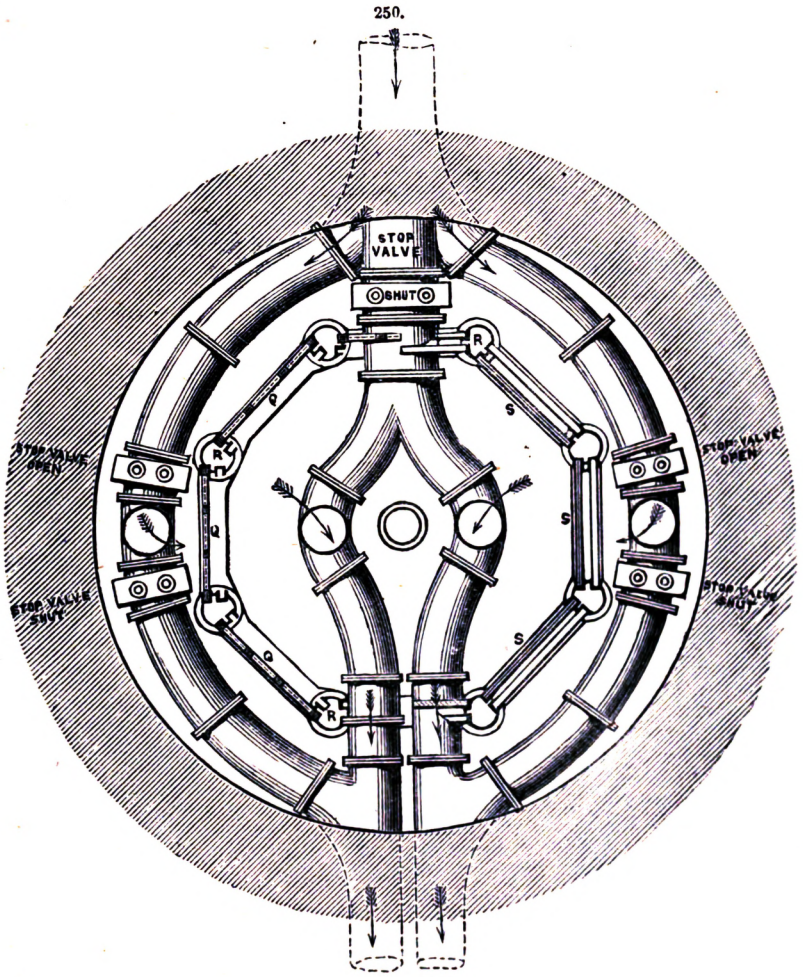

the aqueduct thereby computed, and the quantity of water passing every day into Glasgow is thus known. From the upper pool the water passes into the main reservoir over similar cast-iron gauge-plates. The water is drawn from the reservoir by pipes laid in a tunnel cut through the rock in the solid, at the end of the main embankment, no pipes being laid through the embankments themselves. At the end of the tunnel next the reservoir there is a stand-pipe with valves at different heights, which admit of water being drawn off at various levels. The water passes down the stand-pipe and along a 48-inch pipe in the tunnel for a distance of about 50 yards to a circular straining-well cut in the rock. Water can also be drawn direct from the aqueduct or from the upper compartment of the reservoir into the pipes leading to the city, without passing through the reservoir, by means of a line of 48-inch pipes laid through the bottom of the reservoir from the stand-pipe back to the upper end of the reservoir where the aqueduct enters.

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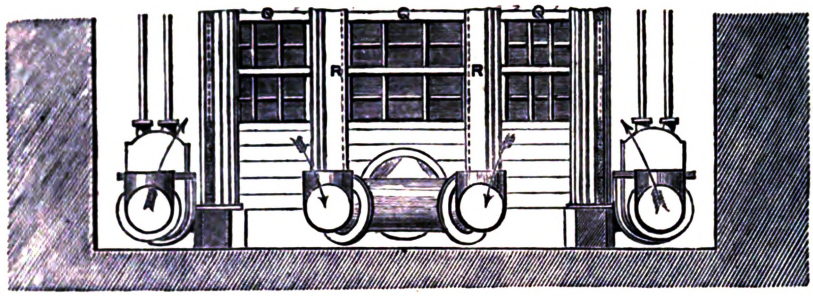


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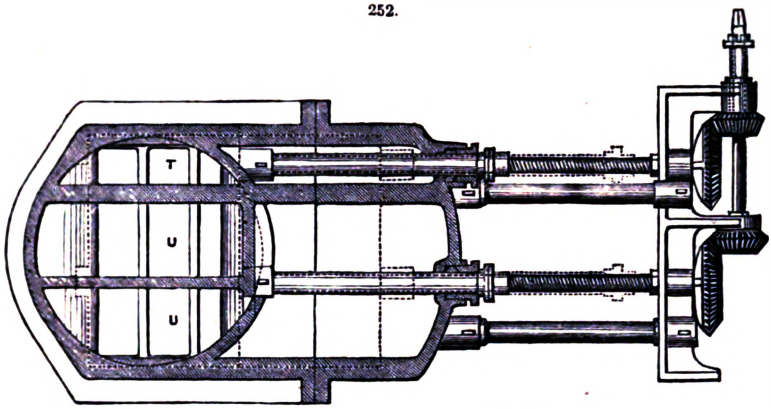


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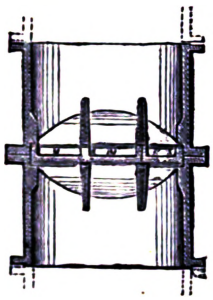

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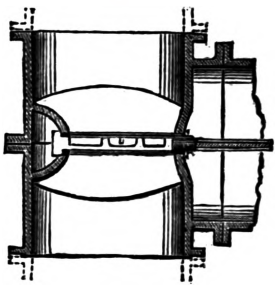


The straining-well is shown in vertical section in Figs. 249, 251; and Fig. 250 is a sectional plan. The well is 40 feet diameter and 63 feet deep, cut out of the solid rock. Within the straining-well, and forming an inner chamber of octagonal shape, 25 feet diameter, a series of oak frames Q Q, Fig. 249, is placed, covered with copper-wire cloth of 40 meshes to the inch; these are held in the light cast-iron pillars R, which have grooves cast in them to receive the frames. These wire-cloth strainers occupy only the lower part of the well, the space above being filled in with wood planking S S, up to the top water-level of the reservoir. The water passes from the outside through the wire-cloth strainers into the inner chamber, and is taken off thence to the city by two lines of cast-iron pipes 42 inches diameter, as shown by the arrows. The water undergoes no filtration, but in passing through these copper-wire strainers, any straws, or other floating matters, are separated from it.

The pipes in the bottom of the straining-well are provided with junctions and stop-valves, as seen in the plan, Fig. 250, so as to admit of the supply being drawn direct from the reservoir, while the strainers are being cleaned; which latter is done by emptying the well, and throwing a

255.



256.



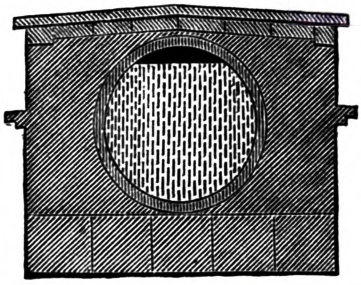
257.

jet of water upon the strainers from the inside outwards, by a leather hose with the head pressure of the reservoir, the foul water being carried off by a tunnel through the rock. The frames Q Q carrying the strainers can also be raised to the top of the well and taken out for repairs, by being drawn up through the grooves in the cast-iron pillars R, in which they are fitted. The top of the straining-well is roofed in and partly covered with glass, as a protection to the working gearing of the stop-valves. These valves are each divided into two halves, affording together a waterway of the full diameter of the 42-inch pipes. Each half of the valve is opened and shut by an iron rod, passing up through a cast-iron pipe, and terminating at a convenient height above the water-level in a long brass nut, into which works a stationary iron screw, turned by a crank and bevel-wheels. The two lines of 42-inch pipes laid in the tunnel, leading off from the straining-well, will deliver the whole 50,000,000 gallons a-day; but on emerging from the tunnel, which is 440 yards long, they are diminished to 36 inches diameter, and provision is made for additional pipes being laid when required. At the point where the pipes are reduced to 36 inches diameter, a self-acting throttle-valve is fixed on each line of pipes, the object of which is to shut off the water coming from the reservoir in the event of one of the pipes bursting, or any other accident occurring whereby the velocity of the water in the pipe is increased beyond that to which the valves are adjusted.

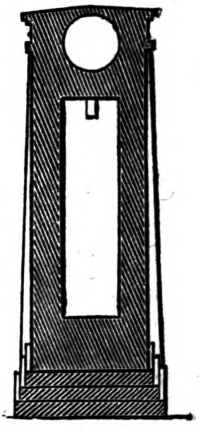
At intervals along the line of the mains to Glasgow and at several points in the city, stop-valves are fixed in the large pipes, one of which, for a 36-in. pipe, is shown in Figs. 252, 253, 254. To admit of these valves being easily closed or opened, the slide is divided into two compartments, T and U, one being considerably smaller than the other. The smaller slide, T, is the first opened, and the passage of the water through this opening so much reduces the pressure upon the larger slide U, that it can be opened with ease; the valve is thus easily worked by one man. To economize space, which is an object where large valves have to be placed in public streets, the total effective area of the valve has been reduced, in the case of these 36-inch valves, from 7 sq. ft., the area of the pipe, to 4½ sq. ft.; the smaller slide, T, having an area of 1 sq. ft., and the larger, U, an area of 3½ sq. ft. To pass this contraction with the velocity that the water in the pipes will have when the discharge is greatest, the loss of head will be from 4 to 6 inches; but this loss is more than compensated for by the economy of the valve and the reduction in the dimensions of all the parts.

The Washington aqueduct, constructed for the purpose of supplying to Georgetown and Washington, U.S., water from the river Potomac, at a point eleven miles above the last-mentioned city, consists for the greater part of its length of a masonry *conduit*, 9 feet in internal diameter. The fall of this conduit averages 9 in. per mile, its length being 11$\frac{1}{15}$ miles. The total length of the aqueduct is 16$\frac{1}{3}$ miles, and it is capable of supplying to the town *reservoir* 100,000,000 gallons a-day. In carrying out this work, all unnecessary expenditure has been avoided by constructing its parts in as simple a manner as possible; thus the various water-gates and pipe-vaults have, in most cases, been arranged within the masonry embankments; and thus, whilst most of the fittings are out of the reach of frost, much of the expense, which would have been incurred by the erection of gate-houses, and so on, above ground, has been saved. The aqueduct-bridge over Cabin John Creek, on the line of the conduit, from the source of supply to the receiving reservoir, is shown in Figs. 255, 256, 257. It is a stone-arched bridge, its clear span is 220 ft. The arch is an arc of a circle of 134·2852 ft. radius, and its rise is 57·2624 ft. Fig. 255 is a side elevation; Fig. 256, longitudinal section; Fig. 257, sectional plan; Fig. 258, transverse section through the eastern *abutment*, taken through the springing of the arch; and Fig. 259, a transverse section through the crown of the arch. The radius of the *extrados* is 143·2695 ft., the depth of the *voussoirs* being 6 ft. 2 in. at the springings, and 4 ft. 2 in. at the crown. Outside the voussoirs is another series of arched stones, which make up the total thickness of arch at the springings to 20 ft., this thickness diminishing towards the crown. The width of the bridge on the face of the arch is 20 ft. 4 in. The abutments are formed by the solid rock on each side of the creek; the face of this rock being stepped down, as shown in Fig. 256, and the steps filled in with concrete, on which the footings of the arch bed. The channel through which the water is conveyed consists of a conduit of circular section, 9 ft. diameter inside and 9 in. thick, this conduit being imbedded in the masonry of the bridge. The haunches and abutments of the bridge are lightened by *relieving arches*, of which there are five on the western and four on the eastern side, extending through half the thickness of the bridge. The centering on which the arch was constructed was supported upon temporary piers, formed in the bed of the creek, as shown in Fig. 256; the vertical timbers bearing upon these piers, and the bracing connecting them, carrying a series of struts radiating to the lines of timbers beneath the lagging-boards. The key-stone was inserted in mid-winter, and the centre was not struck until some ten or twelve months later. The rise of temperature lifted at times the arch of the centering; but when the latter was removed, careful observations were made without any settlement being noticed.

259.



258.



*Works and Reports on Aqueducts*:—Tower's (F. B.) 'Croton Aqueduct,' royal 4to, New York, 1843. Fontenay (T.), 'Construction des Viaducs, Ponts, &c., 2 vols. 8vo, and 'Atlas,' in 4to, 1852. Cautley (Sir P. T.), 'Report on the Ganges Canal Works,' 2 vols. 8vo, 1 vol. 4to, and Plates in

folio, 1860. Becker, 'Der Wasserbau in seinem ganzen Umfange,' 1861. Birot (F.), 'Guide pratique du Conducteur des Ponts,' &c., 2 vols., 12mo, Paris, 1862. Hagen, 'Handbuch der Wasserbau Kunst,' 1863. 'On the Loch Katrine Waterworks,' by Jas. M. Gale: Proceedings Inst. M. E., 1864. Moncrieff (C. C. Scott), 'Irrigation in Southern Europe,' 8vo, 1868.

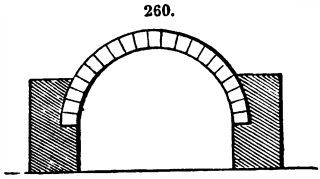
See also:—Belidor, 'Architecture Hydraulique.' Delaistre, 'Encyclopédée de l'Ingénieur. Minard, 'Cours de Construction.' 'Life of Telford,' 4to and fol. Sganzin, 'Cours de Construction.'

ARCH. Fr., *Arche, cintre*; Ger., *Bogen, Gewölbe*; Ital., *Arco*; Span., *Arco*.

An *arch* is a form of structure in which the vertical forces due to the weight of the materials of which it is composed are transmitted to the supports or *abutments* in a polygonal line, usually termed the "curve of equilibrium," from the fact that it becomes a curve when the arch-stones are infinitely numerous.

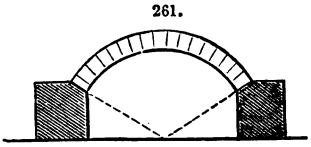
Arches are named from the curve or outline of the under-surface presented by a section taken at right angles to the axis. Thus, an arch whose outline is a semicircle is called a "semicircular arch," and one formed to an elliptical curve is called an "elliptical arch." Figs. 260 to 273 show the forms of arches usually constructed.

260.



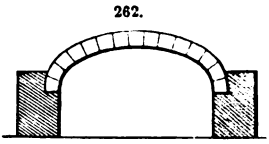
Semicircular Arch.

261.



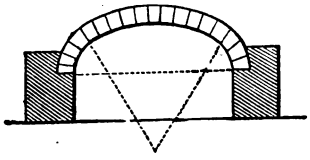
Segmental Arch.

262.



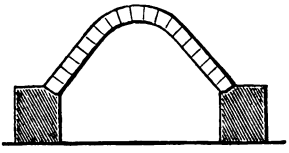
Elliptical Arch.

263.



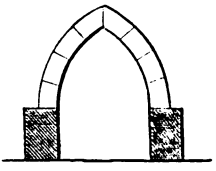
Three-Centre Arch.

264.



Parabolic Arch.

265.

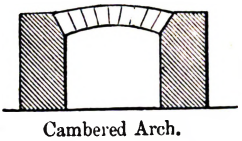


Pointed Arch.

266.

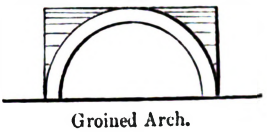
Straight Arch.

267.



Cambered Arch.

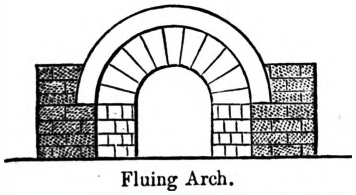
268.



Groined Arch.

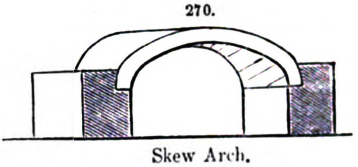
Where two arches intersect, they are called "groined arches."

269.



Fluing Arch.

270.



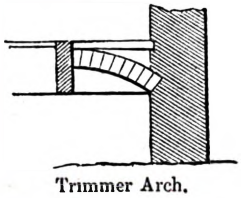
Skew Arch.

Where the opening at one end is less than at the other, as in Fig. 269, the arch is called a "fluing arch."

The terms "gauged" and "axed" are applied to brick arches when the bricks are gauged or axed to shape.

Where the axis of an arch is oblique to the face, it is called a "skew arch."

271.

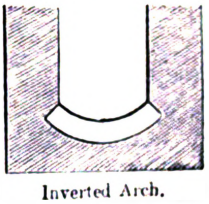


Trimmer Arch.

272.

Relieving Arch.

273.



Inverted Arch.

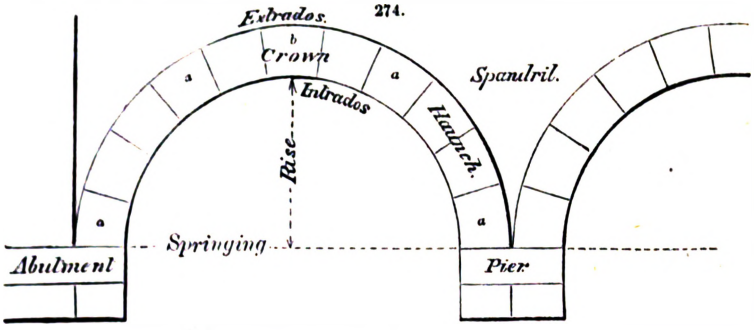
Arches are also named from the use to which they are applied, as "trimmer arch," usually built under the hearths of fire-places, Fig. 271.

"Relieving arch," when placed over a lintel or bressummer to relieve it of the weight of the wall above, Fig. 272.

"Inverted arch," when placed under an opening or space to distribute the pressure of the walls over a more extended area, Fig. 273.

The parts of an arch are named as follows:—

274.




*Extrados.*—The outer surface or back.

*Intrados.*—The inner surface or "soffit."

*Crown.*—The upper part between the extrados and intrados.

*Haunches.*—The flanks or sides between the springing and crown.

*Voussoirs.*—The stones or blocks, *a a*, Fig. 274, of which the arch is formed.

*Key-stone.*—The highest or middle voussoir in the crown, as *b*, Fig. 274.

*Sommering Lines.*—The radiating lines corresponding to the direction of the bed-joints of the voussoirs.

*Springing.*—The level or point of the intrados at which the arch joins the piers.

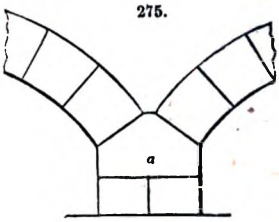
*Spandril.*—The part between two arches springing from the same pier, or between the back of an arch and a perpendicular line erected from the point where the extrados commences at the springing.

*Span.*—The width between the piers at the springing line.

*Rise.*—The vertical distance between the crown and springing.

*Skewback.*—The part of the pier on which a segmental arch rests, or from which it springs, as *a*, in Fig. 275; the lower bed being horizontal, to correspond with the joints of the pier, and the upper bed inclined towards the centre of the arch to correspond with that of the voussoirs.

275.




An arch derives its strength from the fact that, if the ends are prevented from spreading, its curve cannot be shortened except by the crushing of the materials. Hence it is obvious that there are *two* conditions at *least* which are essential to the stability of an arch—immobility of the supports, and sufficient strength in the materials to resist crushing. *Another* condition of equal importance is, that the arch should have sufficient thickness to contain its curve of equilibrium—when all these conditions are fulfilled, the arch is said to be *stable*.

No writer has propounded a theory by which the proper thickness of an arch at the crown can be obtained so as to be of any use in practice. The question involves the depth required for equilibrium, as well as to resist crushing. English engineers, for the most part, adopt an empirical formula, due to J. T. Hurst, 'Building News,' Feb. 27, 1857, and given in Rankine's work on 'Civil Engineering,' but in a slightly modified form.

If D = the depth or thickness of the arch at the crown, R = the radius of curvature, and C = a constant depending on the nature of the material, we have

$$D = C\sqrt{R}.$$

For Block-stone .. .. C = 0·3.
„ Brickwork in mortar „ = 0·4.
„ Rubble-stone in mortar „ = 0·45.

Where the brick or rubble work is built with Portland cement, a lower value of C may be taken, but to what extent there are no experiments at present to show.

For elliptical or other arches, with a varying curvature, R may be taken to represent the radius at the crown.

In a straight arch, D should equal $C\sqrt{S} + \frac{S}{12}$, S being the span of the arch.

According to theory, having obtained the *minimum* thickness D at the crown for an arch in equilibrium, the thickness at any other point, to prevent the arch from blowing up at that point, owing to the thrust, will equal $\frac{DV^3}{v^3}$, V and $v$ being the rise of the arch at the crown, and at the point for which the thickness is required, respectively.

The force of an arch tending to spread, or to thrust out its abutments, is usually resolved, at the springing, into a horizontal direction, termed the "horizontal thrust," and is equal to that at the crown when the arch is in equilibrium.

Various theories have been advanced with the view of determining the value of this force, but most of them are useless to the engineer, from the difficulty involved in their application to practice

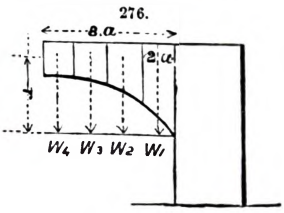
—some fail from the incorrectness of the data on which they are founded, and others because they apply only to a special form of structure instead of being adapted to the form required in practice.

When the thickness and loading of an arch have been properly determined, the horizontal thrust can generally be found with sufficient accuracy by assuming that the tendency of the arch is to separate at the crown and springing, whence

If G = distance from the springing to a vertical line drawn through the centre of gravity of the half-arch,
V = rise of the arch,
W = weight of half-arch,
P = the horizontal thrust in the same terms as W,

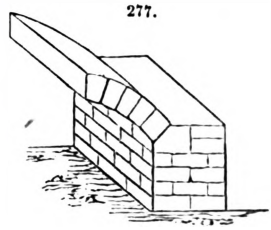
then $$P = \frac{W\,G}{V}.$$

As the centre of gravity is tedious to find, particularly in an arch extradossed to a horizontal line, the following method will sometimes be found convenient. Divide the half-arch into say four equal parts, and call their respective weights, $W_1$, $W_2$, $W_3$, and $W_4$, as in Fig. 276. Conceive the centre of gravity of each point to be in a line drawn vertically through the middle, then the moment of each part tending to overset the pier will be the weight of the part multiplied by the horizontal distance of its centre line from the springing; and if we take the width of each of the parts $= 2a$, and the rise of the arch added to half its depth at the crown $= r$, the horizontal thrust will be nearly




$$P = \frac{W_1 a + W_2 3a + W_3 5a + W_4 7a}{r}.$$

The *abutment*, Fig. 277, is the part which supports and takes the thrust of an arch. It is subject to three conditions:—1st. It should sustain the weight of the arch without crushing. 2nd. There must be sufficient adhesion between the courses of masonry to resist the tendency to slide. 3rd. It should be of sufficient thickness to resist the thrust of the arch without overturning.




The use of granite, the harder limestones, or sandstones, fulfils the first condition in most cases. The second may be attained by the use of dowels, or a good hard-setting cement. When dowels are used, they are usually of copper, iron, or slate, from 1 to 2 inches square, and from 4 to 6 inches long. To fulfil the last condition we must resort to calculation as follows:—

Let H = height of abutment,
T = thickness of ditto,
P = horizontal thrust of half-arch,
W = weight of ditto,
C = weight of a cubic foot of the arch and abutment.

We have $P\,H = \frac{C\,H\,T^2}{2} + W\,T$; or, $T = \sqrt{\frac{2\,P}{C} + \left(\frac{W}{C\,H}\right)^2} - \frac{W}{C\,H}$.

This formula gives the nett thickness of abutment to resist the thrust of the arch, on the supposition that the weight of the half-arch W acts on the inner edge of the abutment, instead of through the centre of gravity. In practice safety is attained by adding counterforts or wingwalls in addition to the thickness attained by the formula.

See BRIDGE, CONSTRUCTION, DOME, &c.

*Works on Arches*:—Atwood (G.), 'Dissertation on the Construction and Properties of Arches,' 2 Parts, 4to, 1801–1804. Gauthey (E. M.), 'Traité de la Construction des Ponts,' 3 vols., 4to, Paris, 1809–1816. Ware (S.), 'Tracts on Vaults and Bridges,' royal 8vo, 1822. Gwilt's (J.) 'Treatise on the Equilibrium of Arches,' 8vo, 1839. Scheffler, 'Theorie der Gewölbe und Futternzauern,' 1857. Woodbury's (Capt. D. P.) 'Treatise on the various Elements of Stability in the Well-proportioned Arch,' 8vo, New York, 1858. Cavalli (G.), 'Memoria sul delineamento equilibrato degli archi in murato,' 4to, Torino, 1859. Breymann, 'Bau Constructions,' Lehve, vol. i., 1860. Bland (W.), 'On the Principles of Construction in Arches, Piers, Buttresses,' &c., 12mo, 1862.

See also:—Rondelet, 'L'Art de Batir.' Sganzin, 'Cours de Construction.' Robison's 'Mechanical Philosophy.' Hann and Hosking, 'Theory, Practice, and Architecture of Bridges.'

ARCHIMEDIAN SCREW, *for raising water.*

ARCHIMEDIAN SCREW. FR., *Vis d'Archimède*; GER., *Archimedische Schraube*; ITAL., *Vite d'Archimede*; SPAN., *Tornillo de Arquímedes.*

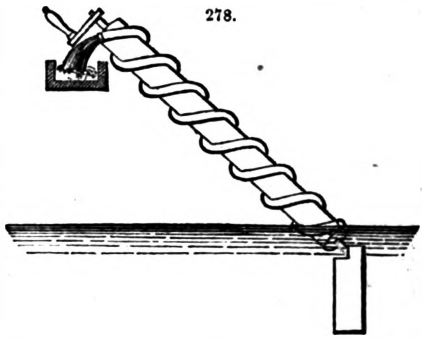
If, upon the surface of a cylinder, a *helix* of several spirals be traced, so that in a groove cut according to this curve are set small plates, all of the same height, and joining well upon each other, the combination will present, as it were, the thread of a screw, perpendicular to the surface of the cylinder, and of uniform thickness. A screw so formed, covered with a cylindrical envelope of staves, will constitute an *Archimedian screw*, for raising water. Its envelope with the barrel, the plates forming the thread of the screw, will be the steps, and the solid cylinder the *newel*, or core; the space comprised between the *newel*, the barrel, and the thread, will form a *helicoidal* canal. In the common screws, three equidistant blocks, or threads, are placed upon the same *newel*, and consequently three canals. The diameter of the screw, which is the interior diameter of the barrel, varies from 1 ft. to 2 ft.; that of the *newel* is a third of it, and the length of the screw is from twelve to eighteen times the diameter, as the strength may require. The angle made by the helix

with the axis, or rather with a right line traced upon the *newel*, and consequently parallel to the axis, has undergone great variations. The Romans made it but 45°; at Toulouse, from plans btained from Holland, it is made about 54°; constructors at Paris generally make this angle 60°; and Eytelwein, in a small screw, carefully made, went as high as 78°. At the upper extremity of the axis there is a crank, and at the lower is a pivot, which is received in a socket, embedded in one of the small sides of the frame of the machine. If we place an Archimedian screw thus constructed in a body of water, giving it an inclination less than that of the helix upon the axis, which is usually from 30° to 45°, and impress upon it a motion of rotation, in an opposite direction to that of the helices, the inferior orifice of the canals passing in the water will draw up a certain quantity, which will rise from spiral to spiral, and will issue at the upper orifice. The screw is particularly adapted to the draining of water from places where we wish to lay, unobstructed by water, the foundations of any hydraulic structure, such as the pier of a bridge, or a lock.

Its simplicity, the small space it occupies, the facility of transporting and setting it up, as well as that of setting up many at the same place, causes its use to be very general in such drainings, and give it a preference even over other machines which have advantages in other respects.

For greater simplicity, let us take a screw, Fig. 278, formed by a tube, bent and wound round a cylinder. We first place it horizontally; if, through the orifice at the base, we introduce a bullet, in rolling, as upon an inclined plane, it will advance towards the other extremity of the tube, and it will stop upon the lowest point of the first spiral. By turning the machine, the point on which it rests will be raised; it will leave it, and, as if descending, it will pass to the following point, and in succession to the others, remaining always at the same level, but advancing towards the outlet of the tube, which it will finally attain, and pass through it. Now, incline the machine a little, and again introduce the bullet through the lower end; it will still settle itself upon the lowest point of the first spiral, when it will be raised by means of the motion of rotation, and will pass upon the following one, which will also be raised, but in a less quantity. In this manner, by a movement at once progressive and ascensional, it will gain the upper outlet: it will have risen by descending, the plane on which it rested rising more than itself. If the inclination of the screw had been such that the helix should present no point lower than that upon which the bullet is first placed, it would have continued to remain there. Finally, if the inclination had been still increased, the bullet could not have entered it; and if it had been introduced through the upper orifice of the tube, it would have descended in following all the windings, and have issued through the lower orifice.

278.



What we have said of the bullet applies equally to the water which enters through the base into the spiral tube. It will flow to the lowest point of the spiral; it will then rise on both sides, in the two branches, to the level of the most elevated point of the branch of entry. The arc of the spiral, containing all the water it can then admit, is the *hydrophoric arc* of the screw. If, after the first spiral is filled, we make a revolution of the machine, the water it contains will advance, like the bullet, with a double motion, progressive and ascensional, and it will be found in the hydrophoric arc of the second spiral; it will be replaced in the first by a new and equal quantity of water. In the following revolutions, these two bodies of water, as well as those which follow after them, will ascend from spiral to spiral, even to the orifice of exit. Thus, at each revolution, the screw will evidently discharge a quantity of water equal to that contained by the hydrophoric arc.

But for this purpose, the base of the screw should be plunged in the well a certain quantity.

It should be at least so much submerged that the mouth of the helicoidal tube, after having traversed in its rotation the water of the well, on its arrival at the surface, shall be found at the summit of the hydrophoric arc of the first spiral; then this arc will be entirely filled; and it is evident that it could not be so if the level of the reservoir was below this point, whose position we shall soon determine. When the mouth, in pursuing its rotation, shall have passed this level, the atmospheric air will enter in the tube, will take the place vacated by the water, and at the end of the first revolution it will fill the upper part of the first spiral, that which is above the hydrophoric arc. It will be the same with the following spirals; the water and the air will be then disposed as indicated by the figure; each of the columns of the former fluid will be entirely supported by its spiral; it will not exert any pressure upon the inferior columns, and throughout the air will have the same density as that of the atmosphere.

It will not be so if the level of the well should be raised above the summit of the hydrophoric arc, even though the orifice of the tube may be found, in some portion of its revolution, outside the water. The air, it is true, will be introduced among the spirals, but the water will occupy more than the hydrophoric arc; it will rise, in the ascending branch, above the summit of this arc, that is to say, above the summit of the descending branch; it will bear upon the inferior column with all this excess, and will compress the air comprised between that and itself. Often this air, striving to regain its density, traverses the column which is above it. On the other hand, and by reason of the movements which take place, and of the irregularity with which the water and the air are reciprocally disposed, the last of these fluids may be found rarefied in certain parts; and we may see the atmospheric air introducing itself in the tube, passing briskly through the water of some spirals, and going to establish the equilibrium; these shocks and irregular movements diminish considerably the product of the machine.

Finally, when the base is plunged entirely in the well, the air cannot enter the screw; nothing but water can enter there. If the velocity of rotation be very great, the centrifugal force resulting

from it may raise this water, and cause it to be discharged through the upper outlet (see TURBINE). But with a less velocity, the water will only reach a certain height in the tube; forming a continuous whole, it will press, with all the weight due to its vertical height, upon the orifice of entry, and will thus counteract the centrifugal force. In great machines, the air which is already in the helicoidal ducts, and that which arrives there through the upper opening, also produce irregularity in the motions, and the diminution of the product already alluded to. When, however, the canals are very large, and the machine is properly disposed and inclined, the exterior air arriving without commotion in all the spirals, these inconveniences no longer occur, and we obtain nearly the usual product.

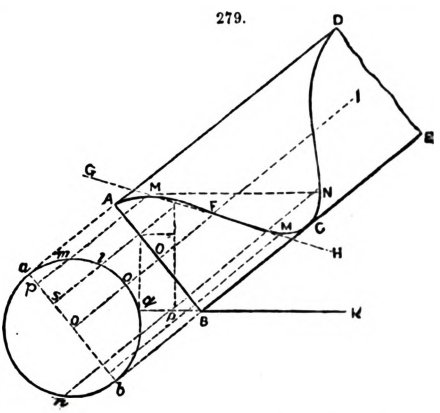
Eytelwein, who made a particular study of the movements of water in different kinds of screws, published a series of experiments which show the bad effect of a too great or too little submersion of the base in the water to be drained; at least, for screws with small *ducts*. We give here some of the results obtained. He was provided with a model of a screw made with great care; it was 0·512 ft. in diameter and 3·608 ft. long: it had two helicoidal ducts, intersecting the axis at an angle of 78° 21′, and having, in the direction of the radius, a height of 0·138 ft. This screw was placed in a reservoir, in an angle of 50° to the horizon; and when it yielded the greatest product, the level was 0·042 ft. above the centre of the base. In the first column of the annexed Table, the height of the water above or below the centre of the base is indicated; and in the second, the volume of water raised at each revolution.

| Height of Level. | Product per Revolution |
|---|---|
| ft. | cub. ft. |
| ·400 | 0·008 |
| ·180 | 0·009 |
| ·082 | 0·009 |
| ·049 | 0·010 |
| ·041 | 0·012 |
| ·032 | 0·011 |
| ·016 | 0·011 |
| ·019 | 0·010 |

Though the Archimedian screw is simple in its character, still there is no theory to be found for the machine as it is now used. The essays of some learned mathematicians are far from enabling us to determine its effects exactly. That which Bernoulli and most authors have given, applies only to the case, now out of use, of a tube, with a very small diameter, rolled spirally round a cylinder. We make an elementary exposition of the principal features of it, both to guide our first impressions upon this subject, and to avoid leaving a gap in this work.

Let A M C N D, Fig. 279, be a vertical projection of the axis of the helicoidal tube, wound round the cylinder A B E D, and the circle $a\,n\,b\,m\,a$ a projection of the base of the cylinder, upon a plane perpendicular to its axis. Through the point F of the arc A M M′ C draw the tangent G H; it will make with the edge O I an angle I F H, which we designate by $a$; and through the extremity B of A B draw the horizontal B K, the angle E B K, or $b$, will measure the inclination of the screw.

279.




Let us determine the length of the hydrophoric arc M C N.

And first, the height L P of any point L of the helix, above the horizontal plane B K. Project L at $l$ upon the circumference of the circle of the base, and draw the horizontal $l\,r$, we shall have $\mathrm{L\,P} = \mathrm{L}\,r + r\,\mathrm{P}$. For greater simplicity make the radius $o\,a = 1$; designate by $a$ the length of the arc $\mathrm{A}\,l\,(= a\,l)$; the angle which the helix makes at A with the plane of the base, being the complement of $a$, we shall find $\mathrm{L}\,r = \mathrm{L}\,l \sin.\ b = \mathrm{A}\,l \cot.\ a \sin.\ b = a \cot.\ a \sin.\ b$. We shall also have $r\,\mathrm{P} = l\,q = l\,\mathrm{B} \cos.\ b = s\,b \cos.\ b = (1 + \cos.\ a) \cos.\ b$. Then $\mathrm{L\,P} = a \cot.\ a \sin.\ b + (1 + \cos.\ a) \cos.\ b$.

The summit or commencement of the hydrophoric arc of the spiral A C D will be at M, the most elevated point above B K. It corresponds consequently to the *maximum* value of L P. Differentiating the above expression, equalling the differential to zero, we have $\sin.\ a = \cot.\ a \tang.\ b$; which gives the value of the arc $a$, or $d\,m$, for the case of the *maximum*. Calling $m$ this particular value at the point M, we have for the height of this point above B K, $m \cot.\ a \sin.\ b + (1 + \cos.\ m) \cos.\ b$.

If through M we imagine a horizontal plane, the point N, where it intersects the ascending branch of the spiral, will be the end of the hydrophoric arc; since the commencement and the end should have the same level. Project N upon the circumference of the base; it will fall upon the point $n$; call $n$ the arc $b\,n$; the arc of the circle $a\,m\,b\,n$, corresponding to the arc of the helix A M C N, will be $\pi + n$; and for the elevation of N above the horizontal plane passing through B, we shall have $(\pi + n) \cot.\ a \sin.\ b + [1 + \cos.\ (\pi + n)] \cos.\ b$.

This elevation should be equal to that of M. Making the two expressions equal and reducing, we have $(\pi + n) \sin.\ m + \cos.\ (\pi + n) = m \sin.\ m + \cos.\ m$: an equation from which we may deduce the value of $n$, by means of successive substitutions.

This value being found, we shall know the arc $m\,b\,n$ corresponding to the hydrophoric arc M C N. But an arc of the helix is equal to an arc of the corresponding circle, increased in the ratio of the radius of the tables to the cosine of the angle comprised between the two arcs, that is to say, divided by this cosine. Here the arc of the circle is $\pi - m + n$, the angle comprised between the two arcs is $90° - a$: the length of the hydrophoric arc will then be $\dfrac{\pi + n - m}{\sin.\ a}$; and, for a cylinder whose radius is $r$,

$$r\,\frac{\pi + n - m}{\sin.\ a}.$$

If $s$ is the section of the helicoidal tube, the volume of water raised at each turn of the screw will be the above expression multiplied by $s$.

Calling N the number of turns made by the screw in a given time, L its length outside of the water, and observing that the height of the elevation is L sin. $b$, we shall have for the value of the useful effect, during this time,

$$N\,L\,s\,r(\pi + n - m)\,\frac{\text{sin. } b}{\text{sin. } a}.$$

The expression sin. $m$ = cot. $a$ tang. $b$, obtained by differentiating, and making equal to zero the general value of the elevation of any point of the first spiral, answers equally to the case of *maximum* and *minimum*; it gives the smallest as well as the greatest elevation. Moreover, the sin. $m$ applies as well to the arc $a\,m'$ as to the arc $a\,m$, by taking $b\,m' = a\,m$. Consequently, if we project the point $m'$ upon the hydrophoric arc, M'. which is its projection, will be the lowest part of the arc, as M is the highest point.

The expression cot. $a$ tang. $b$, representing a sine, cannot exceed 1. When it is equal to it, the arcs $a\,m$ and $a\,m'$ will become $a\,o'$; the points M and M' will be merged in the point F; there will no longer be a hydrophoric arc, and no more water raised. But cot. $a$ tang $b = 1$ gives tang. $b = \frac{1}{\text{cot. } a}$ = tang. $a$ or $b = a$; that is to say, that when the angle of inclination shall be equal to the angle made by the helix with the edge of the cylinder, the discharge will cease; it is necessary, then, in order that it may take place, that the first of these angles should be smaller than the second, as we have already remarked.

That of the values of $b$ giving the greatest effect is impliedly embraced in the above expression of effect. For the same screw, moved with the same velocity, there will be no variable in this expression but sin. $b\,(\pi + n - m)$, and it will be necessary to determine the value of $b$ which will render this quantity a *maximum*.

From what was said at the commencement of this article, in order that the hydrophoric arc should take all the water it can contain, the level of the fluid in the well should be as high as the point $m$, or as the point $p$, which is on the same horizontal line; and consequently should be raised above the centre of the base by the quantity $o\,p = r$ cos. $m = r\sqrt{1 - (\text{cot. } a \text{ tang. } b)^2}$. For the vertical elevation, we shall have

$$r \text{ cos. } b\sqrt{1 - (\text{cot. } a \text{ tang. } b)^2}.$$

In what has been said, we have supposed the hydrophoric arc had time to be filled with water, without any mention of the velocity of the water. It has, however, a great influence upon the amount of the product, especially when the bottom of the screw is entirely submerged. This influence is shown by the experiments of Eytelwein. They were made with the small screw already mentioned, with an inclination of 50°. In the first series, the end of the screw was entirely submerged; an unfavourable circumstance, the disadvantages of which are not sufficiently appreciated by workmen. The second was made under more favourable circumstances, with the base submerged only a suitable quantity. In practice, it will suffice to establish the screw in such a manner as that the end of the vertical diameter of the core may project a little above the surface.

| Number of Revolutions in 1'. | Water raised per Revolution. |
|---|---|
| | cub. ft. |
| 22 | 0·0099 |
| 41 | 0·0094 |
| 51 | 0·0088 |
| 74 | 0·0081 |
| 121 | 0 0068 |
| 56 | 0·0113 |
| 60 | 0·0118 |
| 73 | 0·0121 |
| 85 | 0·0123 |
| 98 | 0·0123 |
| 120 | 0·0118 |

Comparing the terms of the two series, when the velocity of the machine has been nearly the same, we see that when the inferior extremity was entirely submerged, the product was about one-third less.

We pass to the effect of which great screws are capable.

It is made known what this product would be, by giving, in the following Table, the results of experiments made with three pumps, of 1 ft., 1½ ft., and 2 ft. (French measure) in diameter, the latter limit never being exceeded. The length and velocity of each are given, as well as the angle of inclination at which it stopped delivering water; an angle which, according to theory, is equal to that made by the helix with the axis. The greatest effect was produced at an angle of 30°; Morin has taken it for the unit, and has compared with it those obtained under different angles; this comparison shows the great influence of the inclination.

| Angle of Inclination. | Diameter .. .. = 0·066 ft. Length .. .. .. = 19·182 ft. Revolution in 1' .. = 90 Limit of Inclination = 60° | | | Diameter .. .. .. = 1·597 ft. Length .. .. .. = 27·69 ft. Revolution in 1' .. = 60 Limit of Inclination = 62° | | | Diameter .. .. .. = 2·10 ft. Length .. .. .. = 25·57 ft. Revolution in 1' .. = 41⅔ Limit of Inclination = 65° | | |
|---|---|---|---|---|---|---|---|---|---|
| | Water raised in 1 hour. | Height of Elevation. | Series of Effects. | Water raised in 1 hour. | Height of Elevation. | Series of Effects. | Water raised in 1 hour. | Height of Elevation. | Series of Effects. |
| ° | cub. ft. | ft. | | cub. ft. | ft | | cub. ft. | ft. | |
| 30 | 1486·8 | 8·98 | 1·00 | 4576 | 12·36 | 1·00 | 9149 | 10·66 | 1·00 |
| 35 | 1236· | 10·10 | 0·93 | 3630 | 14·62 | 0·94 | 7164 | 13·12 | 0·97 |
| 40 | 872·3 | 11·25 | 0·74 | 2397 | 16·85 | 0·71 | 4841 | 14·90 | 0·74 |
| 45 | 443·8 | 12·36 | 0·50 | 1306 | 19·12 | 0·44 | 2613 | 16·49 | 0·44 |
| 50 | 307·2 | 13·48 | 0·31 | 508 | 20·23 | 0·18 | 893 | .. | .. |
| 55 | 91·8 | 14·62 | 0·10 | 180 | 21·35 | 0·07 | 367 | 17·84 | 0·07 |

Though the volumes of water indicated in the Table have been admitted, as the results of experiment, by a commission of engineers; still, as they are presented by a constructor of the

Archimedian screw, we may fear that there is some exaggeration; and in application, we should not reckon upon more than two-thirds of the product indicated.

It seems that the quantities of water raised by these machines, they having been reduced to the same number of turns in the same time, should be proportional to the capacity of the hydrophoric arc, and consequently to the cube of the diameters, if the screws were similar solids; yet Morin found that these quantities are very sensibly proportional to the $3\frac{2}{3}$ power of the diameter, or to $D^{3\frac{2}{3}}$. Consequently, by reducing one-third the quantities given in the preceding Table, the volumes of water raised in one hour, under different angles of inclination, by a screw of a given diameter D, would be such as are indicated in the adjoining Table.

| Angle of Inclination. | Water raised in 1' by 40 Revolutions. |
|---|---|
| o | cub. ft. |
| 30 | $364\ D^{3\frac{2}{3}}$ |
| 35 | 288 „ |
| 40 | 191 „ |
| 45 | 104 „ |

These screws are usually put in motion by men, who act indirectly upon the crank, through the intervention of beams or connecting-rods, upon which they impress a reciprocal motion which converts that of the crank into a rotatory. What is the number of men to be employed to produce a given effect?

A screw 1·607 ft. in diameter, and 19·19 ft. long, used for draining by M. Lamandé, engineer, moved by nine men (working in spells of two hours, and then relieved by a similar number of fresh hands), inclined about 35°, making forty turns per minute, raised in one hour 1589·2 cub. ft. of water 10·82 ft. For each of the nine workmen, this was 176·58 cub. ft. raised 10·82 ft., or 1910 cub. ft. raised 1 ft.; he did not work over five hours in the day; thus, the day's labour of each was only 9550 cub. ft. In another experiment, six workmen, working six hours, raised each 10,660 cub. ft., and consequently 1776 cub. ft. per hour.

According to these positive and authentic facts, we may admit that a workman, employed upon a well-arranged screw, can raise in one hour 1738 cub. ft. one foot in height, and that he may labour in this manner six hours per day. He might even work eight hours in the twenty-four, in a continuous draining, if the relays were properly established; so that the number of workmen to accomplish such a draining would be $\frac{Q'H'}{579}$, or, to prevent any mistake, $\frac{Q'H'}{463}$, Q' being the volume of water to be raised in one hour, and H' the height of the elevation.

We also employ for draining, screws without the envelope or barrel, consisting simply of a newel, upon which are placed the helicoidal threads. We place them in a canal or semi-cylindrical box enclosure, made of carpentry or masonry, and having a suitable slope: it is, as it were, a half-barrel, but immovable. But a very small interval is left between its sides and the edges of the threads. These machines, called *hydraulic screws* by the Germans, are much used in Holland, where they are frequently set in motion by windmills.

They have a great velocity imparted to them, lest a great quantity of water, raised at first, should fall back into the well, following the sides of the trough, before it has reached the point of discharge. They have the advantage of being independent, in their product, of the height of the water of the reservoir compared to their extremity, and, without shifting their place, they may drain a reservoir whose level is gradually reduced. But this advantage is more than counteracted by an inconvenience: very often the core or newel, at least if it is not large, bends, and the edges of the threads rub against the sides of the canal; which wears out the machine, and occasions a resistance, absorbing a portion of the motive force.

It may be necessary to make brief mention of a machine, which has some resemblance to the Archimedian screw, and which may be used for raising water to great heights: this is the *spiral pump*. It consists of a conical or cylindrical turning-shaft, upon which is wound, screw-fashion, a tube of lead or other material: one of its extremities takes up the water, and the other is enclosed exactly in the curved end of an upright tube, which conveys this water to the desired point.

This machine, invented and made, in 1746, by a tinman of Zurich, has been made the subject of a work by Daniel Bernoulli, who has given its theory, and proposed some improvements, which have been adopted in a construction made at Florence. Since then, Nicander and Eytelwein have devoted their attention to it: the latter reported that, in 1784, he had established such a pump near Moscow, with complete success; it conveys 4 09 cub. ft. in 1 a distance of 761 ft., and 75·46 ft. in vertical height. This author extols all the advantages of this machine, and recommends its use.

When the mouth takes up alternately water and air, these two fluids advance, from spiral to spiral, up to the upright pipe: they enter it; the air is discharged and escapes into the atmosphere, the water ascends gradually. and is discharged through the spout placed at the top of the pipe.

During the motion, the two fluids are disposed in the spirals as shown in the figure; the water on one side, the air on the other—the latter occupying less and less space. In the first spiral from the entrance-mouth the air is loaded, not only with the atmospheric weight, but that of the column of water of the second spiral; the air of the latter sustains also the weight of the third column; and so on; so that in the last spiral, that which is near the upright tube, it is as it were loaded with the weight of a column of water, whose height is the sum of the heights of this fluid in all the spirals. This same air supports, by the elastic force due to such pressure, the column of water in the upright tube; it can therefore support one whose height is equal to the sum of the heights of the water in the spirals. Thus the height to which we can raise water by means of a spiral pump, depends upon the length and the number of spirals of the helicoidal tube.

If the compressed air, on issuing from this machine, were properly received and directed, it would produce a blast, which might easily be made nearly continuous. An Archimedian screw, containing also in its spirals alternate masses of air and water, might yield an analogous effect, if it were disposed and moved in an order in some sort the inverse of that followed in draining. Blast-machines on this principle have been used in many instances with success. The Archimedian screw, in this latter case, is of great diameter compared with its core, and placed in a basin filled with water, with a certain inclination, so that the upper end of the axis shall be very near the

liquid surface. When the screw turns, the upper mouth of the helical canal passing in the atmosphere during one-half of its revolution, there takes a certain quantity of air, which at first has its place above the first hydrophoric axis, and which then descends from spiral to spiral, issues through the lower mouth of the canal, and tends to rise in the water of the basin, with an elastic force measured by the height of the liquid surface above this mouth.

AREA.

The sunk space around the lower stories of a building is termed the area. See MENSURATION.

280.

AREA-DRAIN. FR., *Isolement àiré*. GER., *Luftschicht*.

An area-drain is a narrow open area, Fig. 280, generally less than 3 feet in width, constructed around the basement of a building, to prevent the approach of damp from the surrounding soil.

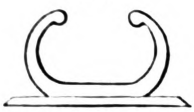
ARGENTAN. FR., *Argentan, alliage de cuivre, nickel et zinc*; GER., *Nickelsilber*; ITAL., *Packfong*; SPAN., *Argentan mezcla de cobre, niquel y zinc*.

Argentan is the name given to an alloy of nickel, copper and zinc; and is generally termed German silver. See NICKEL, *Alloys of*.

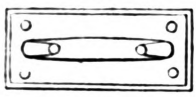
ARM-BAND. FR., *Support à fusil*; GER., *Gewehrhalter*.

An arm-band, Figs. 281, 282, 283, 284, is a piece of crooked iron, attached either to a wooden rail or stone block, fixed against the walls in barrack-rooms, to retain the soldiers' muskets when not in use, the butt-ends resting on the floor. Formerly, muskets were laid horizontally, one over another, in arm-racks, which were not so convenient to reach in cases of emergency.

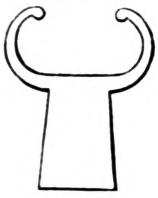
281.



282.



283.



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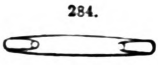
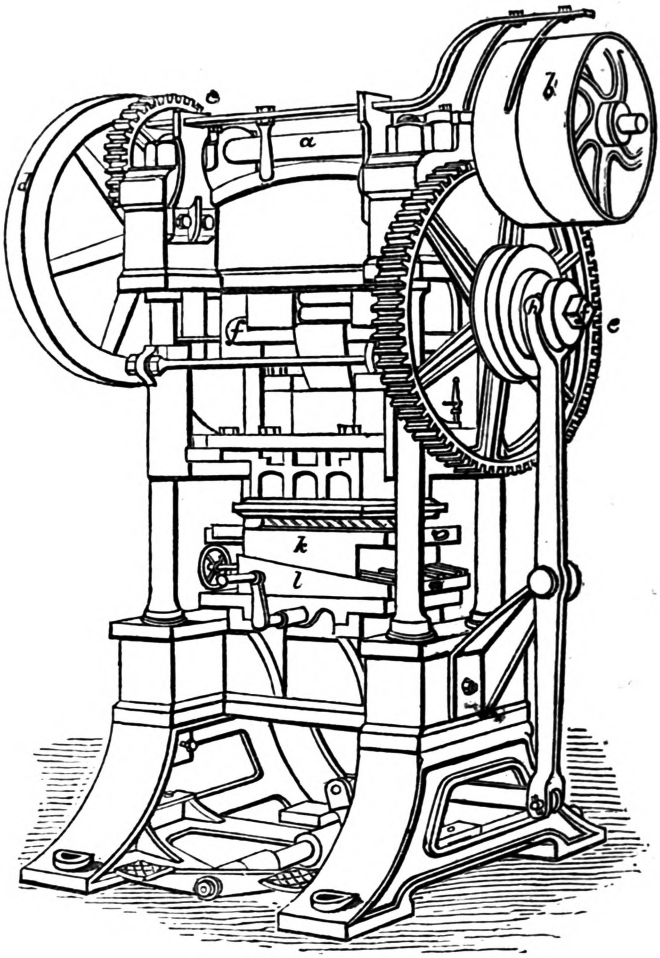


285




ARMING-PRESS. FR., *Presse de carton*; GER., *Deckelpresse*; ITAL., *Torchio da imbozzare*; SPAN., *Prensa para encuadernar*.

An arming-press is a machine used for embossing the back and sides of the cover of a book. Fig. 285 represents the rotary arming-press designed by John Gough, to be worked by steam-power. The shaft, *a*, carrying the strap-pulleys, *b*, is fixed upon the top of the press; and at one end of the shaft is placed a toothed-wheel, *c*, geared into the fly-wheel *d*. On the other end of this shaft is fixed a small pinion, geared into the large wheel, *e*, running loose upon the eccentric shaft *f*. This wheel is fitted on a clutch, *h*, sliding on the square end of the eccentric shaft.

This press, which is of large size, is fitted with two sets of gauges, for feeding front and back, so that, with two attendants, two blocks can be worked at the same time, rendering this press equal to two of a smaller size. The whole is supported by columns, which tie the head and top bearings, bed, and standards, in a compound and rigid manner. The support at each side of the eccentric prevents deflection of the eccentric shaft. The table, *k*, is supported by a sliding-wedge, *l*, the whole of its width, by which arrangement the whole power of the press is concentrated upon the work. The driving-gear and machinery, being placed on the head of the press, renders the usual dangerous gearing on the floor unnecessary.

ARMOUR. Fr., *Armure, Cuirasse;* Ger., *Panzer;* Ital., *Corazzatura;* Span., *Armadura.* Armour-plates *for Ships of War.*

The first account we have of an armoured ship is in 1530 (see 'Istoria della Sacra Religione ed Illustrissima Milizia di San Giovanni Gierosolimitano,' di Giacomo Bosio, pub. 1594). The largest ship then known, one of the fleet of the Knights of St. John, was sheathed entirely with lead, and is said to have successfully resisted all the shot of that day. We have no account of any similar device until the Emperor Louis Napoleon initiated the idea of covering vessels intended to approach forts with iron, in consequence of the general acknowledgment of the impossibility of supporting the effects of shell-fire in ordinary wooden ships, or in thin iron ones when elongated shell are substituted for the spherical ones formerly used. In the United States, trial has been made of superposed plates of 1 and 2 inches thick, up to a total thickness of 8, 13, and 20 inches; but the resistance obtained in this way has never equalled the results where solid plates have been applied.

It has been roughly established that to keep out a hardened projectile fired from a modern rifled gun, the armour-plate must have a thickness at least as great as the diameter of the shot; and the best practice seems to require a solid backing of wood of from twice to four-and-a-half times the thickness of the iron. This will give great resistance when divided into a cellular form by iron edge-pieces or girders, as in the Chalmers' target. An iron lining on the inside is also necessary to diminish the risk of splinters, &c.

Armour-plates are rolled or forged up to the thickness of 20 inches by machinery constructed for the express purpose. They are then bent to the shape necessary by hydraulic-power; and having been planed on the edges and bored with conical holes for the bolts, are attached to the ship's side by long through-bolts, and screwed up with nuts from the inside.

As the artillery have within the last few years advanced with enormous strides in weight and power, it has been necessary to keep pace with these improvements, in the thickness and resisting-power of the armour; and each step forward in the science of artillery has hitherto been met by a corresponding increase in the defences opposed to it. But this cannot go on; and it seems that the limit of defensive armour the ship can carry will be sooner reached than the *ne plus ultra* of the gun or shot that can be brought against it.

It remains to be seen to how much of the ship must be given absolute immunity, and how much may be left to be pierced by shot without fatal consequences. Hitherto the practice has varied from protection over the whole hull with a moderate thickness of armour, to absolute protection confined to a small part of the hull. The Monitor system protects efficiently the hull and guns; but these are little raised above the surface, and the vessel is not intended to keep the sea. The cupola system is an advance on the Monitor, inasmuch as it is applied to vessels of a larger class, and which are seaworthy. But on this plan very few guns are carried in proportion to the tonnage, and the ship requires one special armour and the guns another. There is also the disadvantage that the rigging must be sacrificed if the guns are to be used over a large arc of training.

In 1865 a series of experiments were made by the British Government to determine the relative penetrating effects of two shot on an iron plate, provided they strike with the same *work* or *energy*, notwithstanding the one may be heavy with a low velocity, and the other light with a high velocity; and also to determine the relative resistances of a plate to penetration by two shot of similar form of head, and striking with work proportional to their respective diameters.

For these experiments the charges were determined with the aid of Navez's apparatus, by which the velocity of each projectile was observed at the distance of 100 yards from the muzzle. Cast-iron shot were supplied for this experiment, their weight being the same as the steel shot. The spherical projectiles were shells weighted up with lead.

The following Table shows the velocity which each projectile should have in order that the conditions might be fulfilled.

Table A.—Showing the necessary Velocities and Charges determined by Experiment: 5·5-inch Plates. Projectile, Solid Steel Hemispherical-headed Shot.

| Gun. | No. of Experiment. | Charge determined by Experiment. | Projectile. | | Necessary Velocity at 100 Yards. | "Work" on Impact at 100 Yards. |
|---|---|---|---|---|---|---|
| | | | Mean Weight. | Mean Diam. | | |
| | | lbs. | lbs. | inches. | feet. | foot tons. |
| 6·3-inch m. l. rifle-gun .. .. .. .. | 1 | 15·848* | 35·56 | 6·22 | 1917 | 906·2 |
| " " .. .. .. .. | 2 | 12·000* | 71·12 | " | 1355 | " |
| " " .. .. .. .. | 3 | 11·219* | 106·68 | " | 1107 | " |
| " " .. .. .. .. | 4 | 13·875* | 35·56 | " | 1823 | 819·3 |
| " " .. .. .. .. | 5 | 10·500* | 71·12 | " | 1271 | 796·2 |
| " " .. .. .. .. | 6 | 9·812* | 106·68 | " | 994 | 731·5 |
| 7-inch m. l. rifle-gun .. .. .. .. .. | 7 | 13·500 | 100·00 | 6·92 | 1130 | 885·8 |
| " " .. .. .. .. .. | 8 | 11·625 | " | " | 1022 | 724·8 |
| 100-pr. m. l. smooth-bore gun (9-in.) .. | 9 | 15·437† | 104·00 | 8·87 | 1254 | 1135·4 |
| " " " .. | 10 | 11·125† | " | " | 1135 | 929·0 |

* Charge, powder nearly half the weight of shot.

† Charge, powder one-seventh the weight of shot.

The charges having been thus ascertained, the guns used were placed in battery, at 100 yards from a row of 5½-in. iron plates, fixed by upright supports, but unbacked. The guns were fired directly at the plates; that is, the plane in which the shot moved was perpendicular to the face of the plates.

TABLE B.—ABSTRACT, SHOWING THE RESULTS OF THE EXPERIMENTS CARRIED OUT AT SHOEBURYNESS, 22/3/65, AGAINST 5·5-INCH UNBACKED PLATES.

1000 to 1010 show Effect of Equality of *vis viva* where V and W vary. In the last three rounds the charges were altered on the ground, and the effects are not comparable:—

| | | | | | |
|---|---|---|---|---|---|
| 35 lbs | Shot, | Spherical, | Length, | 6·220 | inches. |
| 63 „ | „ | Elongated, | „ | 8·500 | „ |
| 70 „ | „ | „ | „ | 9·315 | „ |
| 106 „ | „ | „ | „ | 13·458 | „ |

} Hemispherical-headed.

| Photographic Number of Round. | Charge. | Weight of Projectile. | Velocity on Impact. | Approximate $\frac{Wv^2}{2g}$ in Foot Tons on Impact. | Effects with Steel Projectiles of 6·22-in. Diameter, fired from the 6·3-in. Gun of 140 cwt., R., Expl. No. 275. |
|---|---|---|---|---|---|
| | lbs. | lbs. | feet. | | |
| 1000 | 15·848 | 35·875 | 1920·0 | 917·0 | Clean hole *through* plate, and 3 ft. 2 in. into earth. |
| 1003 | „ | 35·562 | 1925·0 | 913·8 | „ „ and stopped by a balk of timber. |
| 1001 | 12·000 | 63·687 | 1417·0 | 886·7 | „ „ and 3 ft. 6 in. into earth. |
| 1004 | „ | 70·937 | 1345·0 | 889·8 | Struck left edge of plate and broke in three pieces. |
| 1006 | „ | 71·250 | 1346·0 | 895·1 | Clean hole *through* plate, and 5 ft. 6 in. into earth. "Earth loosened by former shot." |
| 1002 | 11·219 | 106·625 | 1110·0 | 911·0 | Clean hole *through* plate, and 3 ft. 3 in. into earth. |
| 1007 | „ | 106·812 | 1112·0 | 915·8 | „ „ depth in earth not known. |
| 1008 | 13·875 | 35·562 | 1829·0 | 824·9 | „ „ about 1½ ft. into earth. |
| 1009 | 10·500 | 70·875 | 1270·0 | 792·7 | Stuck in plate; base projects 3¼ in. from face of plate; slight star in rear; outer lamina off plate. |
| 1010 | 9·812 | 106·562 | 996·0 | 733·1 | Stuck in plate; base projects 7 in. from face of plate; part of shot showing through in rear. |

TABLE C.—TO DETERMINE THE RELATIVE RESISTANCES OF A PLATE TO PENETRATION BY TWO SHOT OF SIMILAR FORM OF HEAD, AND STRIKING WITH VIS VIVA PROPORTIONAL TO THEIR DIFFERENT DIAMETERS. SOLID STEEL SHOT, HEMISPHERICAL-HEADED.

| Photographic Number of Round. | Gun. | Charge. | Projectile. | | Velocity on Impact. | Approximate $\frac{Wv^2}{2g}$ in Foot Tons on Impact. | $\frac{Wv^2}{2g}$ as proportional to Diameter. | Effects. |
|---|---|---|---|---|---|---|---|---|
| | | | Weight. | Diam. | | | | |
| | | lbs. | lbs. | inches. | feet. | | foot tons. | |
| 1011 | 100-pr. smooth-bore. | 15·437 | 104·125 | 8·87 | 1254·0 | 1135·4 | 1135·4 | Clean hole *through* plate, and 3 ft. 3 in. into earth. |
| 1009 | 6·3-inch M. L. | 10·500 | 70·875 | 6·22 | 1270·0 | 792·7 | 796·2 | Stuck in plate; base projects 3¼ in. from face of plate. Nose was nearly through. |
| 1027 | 100-pr. smooth-bore. | 11·125 | 104·000 | 8·87 | 1135·0 | 929·0 | 929·0 | Shot rebounded, indent 3·25 in. deep; plate bulged and cracked in rear, over an area of 1 ft. 2 in. by 1 ft. Same plate as 1002, 1003, 1009. |
| 1012 | 7-inch M. L., No. 217. | 11·625 | 100·312 | 6·92 | 1004·0 | 701·1 | 724·8 | Shot rebounded, indent 0·655 in. deep, 7·33 in. diameter; plate cracked in rear; shot much cracked. |
| 1013 | „ | „ | 100·125 | | 1012·0 | 711·0 | 724·8 | Shot rebounded, indent 4 in. deep, 7·1 in. diameter; plate cracked in rear. |
| 1011 | 100-pr. smooth-bore. | 15·437 | 104·125 | 8·87 | 1254·0 | 1135·4 | 1135·4 | Clean hole *through* plate, and 3 ft. 3 in. into earth. |
| 1026 | 7-inch M. L., No. 217. | 13·500 | 100·312 | 6·92 | 1131·0 | 889·7 | 885·8 | Clean hole *through* plate; shot struck and broke support of wood 1 ft. square, and fell in rear. Same plate as 1000, 1004, 1010. |
| 1008 | 7-inch B. L. | 12·000 | 110·000 | 6·88 | 1090·0 | 906·2 | 906·2 | Just penetrated the plate; 2 ft. into earth. Brown's steel. |
| 765 | 6·3-inch M. L. | 13·875 | 35·562 | 6·22 | 1829·0 | 824·9 | 819·3 | Just *penetrated* the plate; 1½ ft. into loose earth. |
| 1009 | „ | 10·500 | 70·875 | „ | 1270·0 | 792·7 | 819·3 | See above. Did not penetrate; base 3¼ in. out. |
| 908 | 68-pr. smooth-bore. | 16·000 | 72·000 | 7·91 | 1365·0 | 930·2 | 930·2 | Indent 2·8 in.; plate cracked behind. Firth steel. *Minute* 14,082. |
| 1010 | 6·3-inch M. L. | 9·812 | 106·562 | 6·22 | 996·0 | 733·0 | 731·5 | Stuck in plate. |

It appears from these Tables, round 1008, that a 6·22-in. projectile is *just* able to penetrate a 5½-in. plate, with a *work* on impact of about 825 foot tons; and assuming that the resistance of the plate varies as the square of its thickness, we shall have the following proportion to determine the work necessary to penetrate a 4½-in. plate with the same projectile; that is

$$5 \cdot 5^2 : 825 :: 4 \cdot 5^2 : x, \text{ and } x = 552 \text{ foot tons.}$$

Experiments against 4½-in. unbacked plates, under similar conditions to those detailed in the experiments against 5½-in. plates :—

TABLE D.—ABSTRACT, SHOWING THE RESULTS OF EXPERIMENTS CARRIED OUT AGAINST 4·5-INCH UNBACKED PLATES TO DETERMINE THE RELATIVE PENETRATING EFFECT OF PROJECTILES OF THE SAME DIAMETER AND FORM OF HEAD, BUT SO VARYING IN WEIGHT AND VELOCITY THAT THE VIS VIVA ON IMPACT WAS CONSTANT.

*Date of Experiment*, 13/3/66. *Brand of Powder*, Rifle L. G. 8/7/64. *Lot* 805.

| Photographic Number of Round. | Number of Plate. | Charge. | Weight and Length of Projectile. | Observed Velocity at 220 Feet. | Calculated Velocity on Impact at 300 Feet. | Approximate $\frac{W v^2}{2g}$ in Foot Tons on Impact. | Effects with Hemispherical-headed Steel Projectiles of 6·22-in. Diameter, fired from the Service 64-pr. M. L. Gun of 6·3-in. calibre. |
|---|---|---|---|---|---|---|---|
| | | lbs. | | feet. | feet. | | |
| 1047 | .. | 6·69 | 63·87 lbs. 8·42 in. | 1121·2 | 1112·2 | 547·8 | Just penetrated. Shot rebounded about 6 yards; length of shot 8·05 in. Preliminary round. |
| 1158 | 1 | 6·63 | 63·87 lbs. 8·42 in. | 1128·3 | 1119·3 | 554·8 | Just penetrated; broke plate behind in the usual manner; shot rebounded 4 ft.; length of shot 7·92 in.; diameters of hole 6 × 6·25 in. |
| 1159 | 1 | ,, | 70·94 lbs. 9·3 in. | 1077·7 | .. | .. | Miss. Struck support of plate, and glanced off into the earthwork. |
| 1160 | 1 | 6·09 | 106·19 lbs. 13·39 in. | 864·1 | 860·5 | 545·2 | *Through* plate, breaking away rear in the usual manner. Shot fell 2 ft. in rear; length of shot 12·92 in.; diameters of hole 6·75 × 7·5 in. |
| 1161 | 1 | 7·87 | 35·50 lbs. 6·22 in. | 1483·6 | 1460·0 | 524·7 | Stuck in plate, breaking it away behind; shot almost through. |
| 1162 | 2 | 8·00 | 35·56 lbs. 6·22 in. | 1506·7 | 1482·4 | 541·8 | Just penetrated; broke plate behind in the usual manner; shot rebound d 4 ft.; diameter of shot 6·32 in.; diameters of hole 6·4 × 6·5 in. |
| 1163 | 2 | 6·63 | 70·94 lbs. 9·3 in. | 1069·2 | .. | .. | Miss. Struck support, and glanced into earthwork. |
| 1164 | 2 | ,, ? | 63·81 lbs. 8·42 in. | 1107·1 | 1098·2 | 533·6 | Almost penetrated; broke away plate behind over an area of 1 ft. by 1 ft. Shot rebounded 5 ft. 9 in. Indent 4·35 in.; length of shot 7·88 in. Plates XIII., XIV. |
| 1165 | 2 | 6·06 | 106·62 lbs. 13·39 in. | 861·3 | 857·7 | 543·9 | Stuck in plate, breaking it away at back something more than round 1164; shot almost through. |
| 1166 | 3 | ,, | ,, | 863·1 | 859·5 | 546·2 | *Through* plate. Shot turned over and entered earthwork to a depth of 1 ft.; length of shot 18·96 in. |
| 1167 | 3 | 8·00 | 35·50 lbs. 6·22 in. | 1509·2 | 1484·9 | 542·8 | Made a hole clean through, but shot remained sticking in the plate, projecting as much in rear as in front. |

On examining this Table it appears that all the projectiles but one struck with "work" slightly under that which was required, *viz.* 552 foot tons; and that 542 tons is only just capable of piercing a 4·5-in. plate. Thus in most instances the shot, *after penetration*, rebounded, and fell in front of the plate, showing that they had expended almost their entire force in the penetration. As 552 tons was calculated on data supplied by a shot, round 1008, which penetrated, *and had some little force left in it*, it is to be expected that a force of 542 tons should act as it did. It appears that a reduction of two ounces in the charge, and consequent diminution of "work" to 525 foot tons, was sufficient to prevent complete penetration, round 1161, although it apparently required but a small blow with a hammer to separate the piece of plate at the back of the point struck. As this effect was produced by the shot moving with the highest velocity, it is a convincing proof that, with steel shot, the penetration is not proportional to a higher power than the square of the velocity.

From these experiments the following *practical* conclusions may be drawn when the projectiles are fired *direct*:—An unbacked wrought-iron plate will be perforated with equal facility by solid steel shot, of similar form of head, and having the same diameter, provided they have the same *vis viva* on impact; and it is immaterial whether this *vis viva* be the result of a heavy shot and low velocity, or a light shot and a high velocity, within the usual limits of length, and so on, which occur in practice. An unbacked iron plate will be penetrated by solid steel shot of the same form of head but different diameters, provided their striking *vis viva* varies as the diameter, nearly, that is, as the circumference of the shot. That the resistance of unbacked wrought-iron plates to absolute penetration by solid steel shot of similar form and equal diameter, varies as the square of their thickness, nearly.

These experiments have proved that, although in the case of cast iron a light projectile moving with a high velocity will indent iron plates to a greater depth than a heavier projectile with a low velocity, but equal "work," it is not as necessary that there should be a high velocity when the projectiles are of a hard material, such as *steel* and *chilled iron*; and this result will be much in favour of rifled guns, by enabling them to prove effective with comparatively moderate charges

Putting these results in an algebraic form, and taking the units as the pound and the foot,

$$\frac{W v^2}{2g} = 2\pi R k b^2, \qquad [1]$$

where W = weight of shot in lbs., $v$ = velocity on impact in feet, $g$ = the force of gravity, 2R = diameter of shot in feet, $b$ = thickness of unbacked plate in feet, $k$ = a coefficient depending on the nature of the wrought iron in the plate, and the nature and form of head of the shot.

The shot is supposed to be of the best quality of steel, and the plate of the best quality of wrought iron.

Solving equation [1] for $b$,

$$b = v\sqrt{\frac{W}{4\pi R g k}}, \qquad [2]$$

and for $k$,

$$k = \frac{W v^2}{4\pi R g b^2}. \qquad [3]$$

In order to determine $k$, a series of equations can be formed of the following conditions:—

$4\pi R g b^2 k - W_1 v_1^2 = 0$, $4\pi R_2 g b^2 k - W_2 v_2^2 = 0$, $4\pi R_3 g b^2 k - W_3 v_3^2 = 0$, &c. &c. &c.

Substituting the experimental values of the different quantities, and eliminating $k$, it will be found that for hemispherical-headed shot $k = 5{,}357{,}200$.

Having thus determined the value of $k$, the work necessary to penetrate any unbacked plate of given thickness can be calculated.

Thus, to determine the *work* required to just penetrate a 5·5-in. plate, with a hemispherical-headed steel shot of 6·22 in. diameter,

$R = 3{\cdot}11$ in. $= 0{\cdot}25917$ ft. $\quad b = 5\ 5$ in. $= 0{\cdot}45833$, $\quad k = 5{,}357{,}200$;

and substituting these values in equation [1],

$$\frac{W v^2}{2g} = 1{,}832{,}522 \text{ lbs.} = 818 \text{ foot tons.}$$

It will be seen that round 765, consisting of a spherical shot of 35·56 lbs. and 6·22 in. diameter, moving with a velocity of 1829 ft., and consequent *work* of 825 foot tons, just penetrated a 5·5-in. plate. This *work* is practically the same as that given in the above example, as a difference of 5 ounces in the weight of the shot would have reduced its *work* to 818 foot tons.

*Oblique Fire.*—Suppose the plate set at an angle, or the gun fired obliquely at an upright plate. The shot has then a tendency to glance off, and continue its motion in a new direction.

The force with which the shot, acting obliquely, will strike, is to that with which it would strike if acting directly as the sine of the angle of incidence is to unity. That is, the shot striking in a slanting direction may be supposed to have opposed to it a plate of a thickness equal to the diagonal formed by the line of direction.

TABLE E.—SHOWING THE RESULTS OF PRACTICE WITH STEEL PROJECTILES FIRED AT 4·5-INCH UNBACKED PLATES, PLACED AT AN ANGLE.

| No of Rounds. | Target. | Gun. | Charge. | | Projectile. | | | Striking Velocity. | $\frac{Wv^2}{2g}$ in Foot Tons on Impact. | Foot Tons per Inch of Shot's Circumference. | Observed Effects. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Weight. | Brand of Powder. | Nature and Length. | Weight. | Diameter. | | | | |
| | | | lbs. | | | lbs. | in. | feet. | | | |
| 1 | 4·5-inch unbacked plate at an angle of 38°. | 70-pr. M. L. Armstrong competitive gun. | 14·0 | Rifle L. G. | Cylindrical steel shot. | 70·0 | 6·34 | 1470·0 | 1049 | 52·7 | Struck centre of plate; made an indent 15 in. long and 7 in. broad, and a hole about 2 in. square through the plate. Two large pieces were torn off the back of the plate and driven to the rear. Shot broke up. |
| 2 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Made an indent 14 in. long, 4½ in. deep, and 6½ in. broad; plate cracked through and opened out at back, from which a large piece was torn. Shot broke up. |
| 3 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Made an indent 14 in. long, 7 in. broad, and 5½ in. deep. Back bulged and cracked through. A large piece of the back torn off. Shot broke up. |
| | | | drams. | | | | | | | | |
| 2 | Unbacked ¾-inch plates placed at angles of 60°. | Wall piece | 10 | Rifle F. G. | Cylindrical steel shot with flat head. | 0·344 | 0·87 | 1141 | 3·1051 | 1·136 | Indent 0·53-in. Plate bulged behind. |
| | ° | | | | | | | | | | |
| 2 | 45 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Indent 0·68-in. Bulged as before. |
| 2 | 30 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Indent 0·50-in. Slight bulge behind. |
| 2 | 20 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Indent 0·54-in. No bulge behind. |
| 2 | 10 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | Small piece of plate scooped out. No bulge behind. |
| | | | lbs. | | | | | | | | |
| 630 | 2·5-inch plate unbacked (upright). | 12-pr. B. L. Whitworth gun. | 1·75 | Rifle L. G. | Flat-headed steel shot. | 12·1 | {2·97 2·71} | 1264 | 134·05 | 14·64 | Through plate and into earth-butt behind. |
| .. | Do. at 45° | ,, | ,, | ,, | ,, | 12·1 | ,, | ,, | ,, | ,, | Clean hole through plate, but not sufficient to admit shot, which rebounded. |
| .. | ,, | ,, | ,, | ,, | ,, | 12·1 | ,, | ,, | ,, | ,, | Struck near above round, clean hole through; shot fell inside at foot of plate. Not fair hit. |
| .. | Do. upright | 12-pr. M. L. Whitworth gun. | 1·50 | ,, | ,, | 12·1 | ,, | 1120 | 105·25 | 11·49 | Penetrated plate. |

Equation [1] will therefore become $\frac{W v^2}{2g} = \frac{2\pi R k b^2}{\sin.^2 \theta}$, [4]

and [2] $b = v \sin. \theta \sqrt{\frac{W}{4\pi R g k}}$. [5]

It appears from this that the resistance of the plate increases as the value of $\theta$ diminishes.

It has already been shown that a 4·5-in. unbacked plate when fired at direct, requires a force represented by 28 foot tons per inch of shot's circumference to ensure penetration.

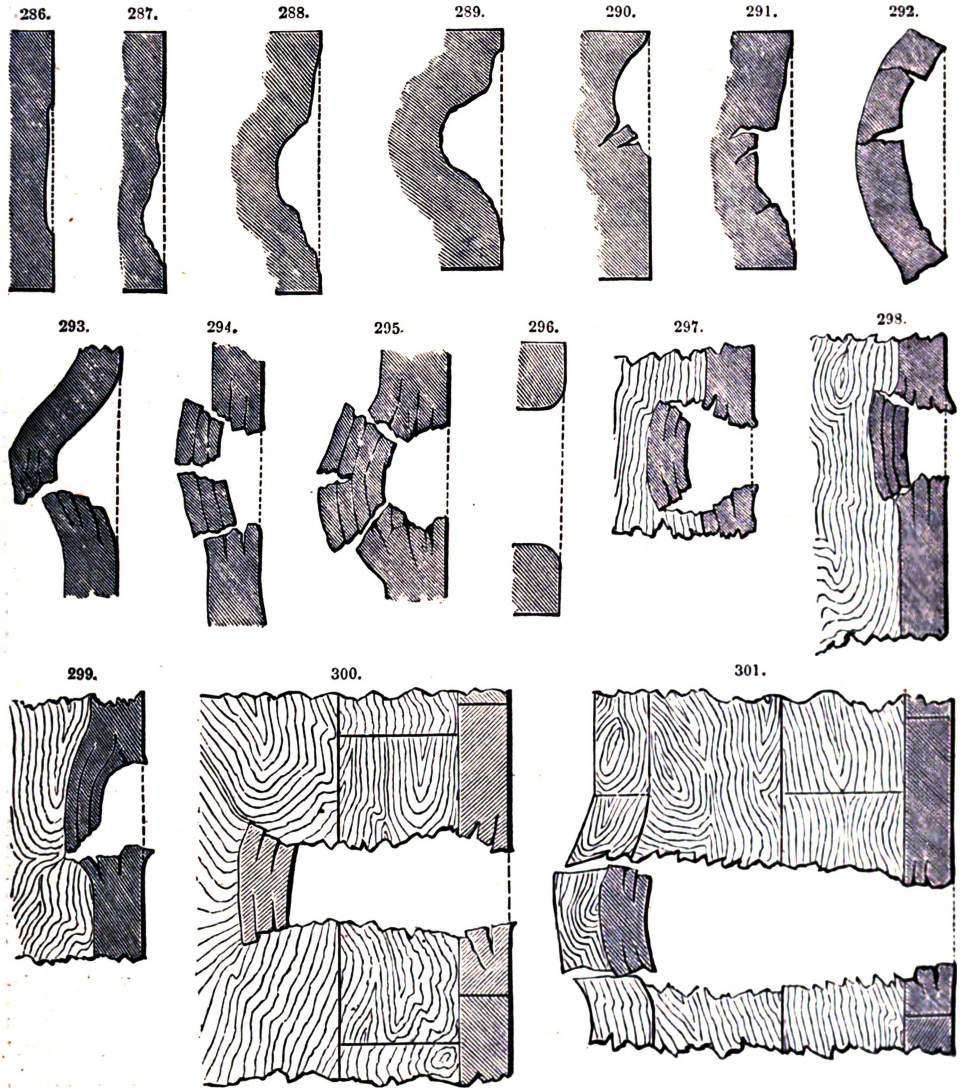
Suppose, however, that the plate is placed in such a position that it makes an angle of 38° with the ground. From equation [4] the force required to penetrate it in this position amounts to 1445 foot tons for a shot of 6·22 in. diameter, or 73·9 foot tons per inch of shot's circumference.

An experiment of this nature was actually tried by the Armstrong and Whitworth Committee. They caused 4·5-inch plates to be set up at an angle of 52° with the vertical, and fired at them from 200 yards' distance with the competitive Armstrong and Whitworth guns.

Table E gives the results of this experiment.

It appears that the projectiles were solid steel shot of 70 lbs. weight and 6·34 in. diameter; that they struck with a "work" of 1049 tons, or 52·7 tons per inch of shot's circumference, and that they *failed to pass through*, although the plate was cracked and opened at the back.

In all these experiments it is to be observed that the life of a smooth-bored gun firing charges of $\frac{1}{3}$ the spherical steel shot's weight will be more than equal to that of a rifled gun firing charges of $\frac{1}{8}$, if the guns are of equally good construction. Consequently, that the work done by the smooth-bore in these examples is not to be taken as absolute proof of what might be done with higher, yet safe charges.



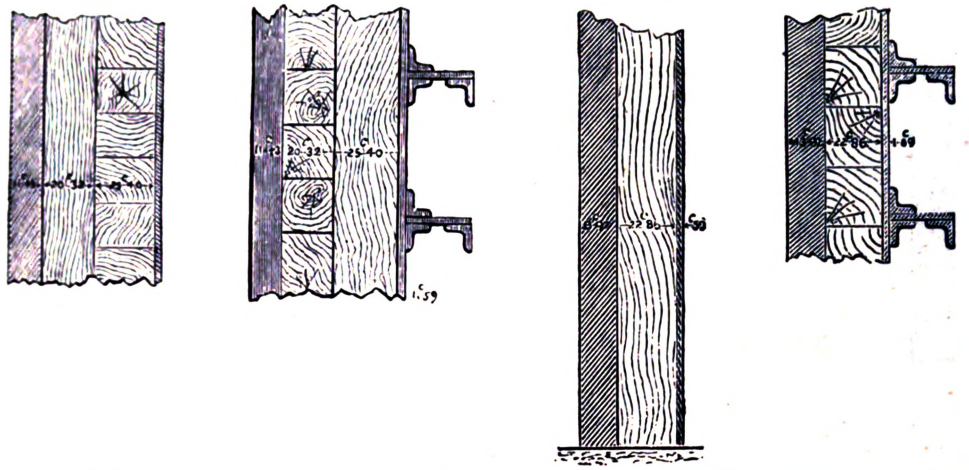

Figs. 286 to 301 exhibit the various effects of projectiles upon armour-plates, and upon armour-plates backed with wood.

Figs. 302 and 303 represent a cross-section and plan of the armour-plated British vessels 'Warrior,' 'Black Prince,' 'Defence,' 'Achilles,' 'Resistance,' 'Hector,' 'Valiant,' and 'Prince Albert.' The ships themselves are constructed of iron plates, ⅜-in. thick, and strengthened by iron ribs at intervals of 18 in. Outside these plates are two layers of teak-planking, making together a thickness of 18 in. Outside the planking, rolled iron plates, 4½ in. in thickness, are placed, and the whole structure is strengthened and held together by strong iron braces. From various experiments made by the British Government, it has been found that a 7-in. muzzle-loading gun, of 130 cwt., with a solid shot of 100 lbs., with a charge of 25 lbs., is capable of piercing the side of the 'Warrior' up to a range of 600 yards.

The 100-pounder smooth-bore gun, 9-in., of 125 cwt., with a solid spherical steel shot of 104 lbs., and 25 lbs. charge, is not capable of piercing the 'Warrior' at any distance over 100 yards.

The 9·22-in. rifled gun, of 12 tons, with a solid elongated steel shot of 221 lbs., and charge of 44 lbs., is capable of piercing the 'Warrior' up to 2000 yards. The 10·5-in. rifled gun, of 12 tons, with a solid elongated steel shot of 301 lbs., and charge of 45 lbs., is capable of piercing the 'Warrior' up to a range of 2000 yards. All these assertions of piercing at long ranges, for example at 2000 yards, are given from calculation, not from actual experiment, and ignore the angle at which the shot must strike, owing to its trajectory at these ranges. The American 15-in. gun, of 22 tons, with a spherical steel shot of 484 lbs., and a charge of 50 lbs., is capable of piercing the 'Warrior' up to a range of 500 yards. The American smooth bore 11-in. and 9-in. guns, fired with solid spherical steel shot and their maximum charges, are not capable of piercing the 'Warrior' at any range.

302. 303. 304. 305.



Figs. 304 and 305 are a cross-section and plan of the 'Minotaur,' 'Agincourt,' and 'Northumberland.' The inner skin of these vessels is the same as that of the 'Warrior.' The backing consists of 9 in. of teak, and is covered outside with plates 5½ in. thick. This armour-plating is fastened by three rows of heavy coned bolts, most of which pass through all the skins. A strip of iron 1·25 in. thick is fastened in rear at the junction of the plates. The rest of the construction is similar to that of the 'Warrior.'

From experiments made on a target of this construction, the results obtained were nearly the same as those obtained from the 'Warrior' target.

Figs. 306 and 307 show the construction of the 'Bellerophon' target. *a* is a plate 6 in. thick, forming the exterior covering, which is followed by a 10-in. backing of teak, worked longitudinally on the skin-plating, between the angle-iron stringers, and bolted with nut and screw bolts through the skin-plating. The latter is composed of two thicknesses of ¾-in. plating, with a layer of painted canvas between. The target is shown in the figure as it was erected for the purpose of experiment, supported by the Fairbairn target, so as to resemble the conditions of a ship's side as nearly as possible. This target was not subjected to a severe test: the most severe blow it was subjected to being from the 10·5-in. rifled gun, with a spherical steel shot of 165 lbs., and charge of 35 lbs.

This shot failed to penetrate the target; but there is no evidence to prove that the 10·5-in. gun would not have penetrated with a charge of 50 lbs.

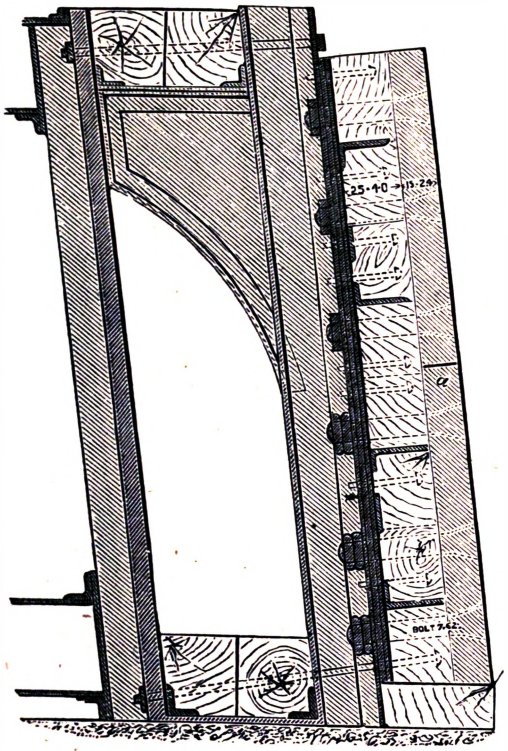
Figs. 308 and 309 are a cross-section and plan of the British men-of-war 'Lord Warden' and 'Lord Clyde.' The frame-timbers of these ships are of English oak, 12½ in. thick, and are connected by iron diagonals 6 in. by 1¼ in. The inner planking is of the best English oak, 8 in. thick, and is covered with an iron skin of 1½ in. The outer teak-planking has a thickness of 10 in., and the armour-plate protecting it of 4½ in. The bolts sustaining the armour-plates are 2½ in. in diameter; their heads press against iron washers, which, in their turn, rest upon india-rubber washers let into the timber.

From the tests to which this target was subjected, it may be concluded that the 7-in. muzzle-loading rifled gun, fired with a solid elongated steel shot of 100 lbs., and charge of 25 lbs., is not capable of piercing the 'Lord Warden' at any range. The 9·22-in. rifled gun, of 12 tons, fired with elongated steel shot of 221 lbs., and 44 lbs. charge, is capable of piercing the 'Lord Warden' up to a range of 100 yds.

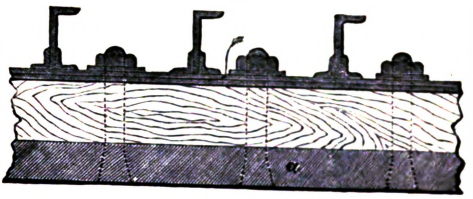
Figs. 310 and 311 show a target representing the construction of the French ironclads 'La Gloire' and 'La Flandre,' both of which are wooden ships protected by armour-plates placed in four rows. The dimensions of the plates forming the two upper rows are 5 ft. 9 in. by 2 ft. 7 in., thickness

4¾ in., and of the two lower rows 5 ft. 9 in. by 2 ft. 5 in., thickness 5 $\frac{9}{10}$ in.; inner planking 6 in., outside planking 10 in. This target was completely pierced by a 259 lbs. cylindrical chilled cast-iron projectile, shot from a 9·22 in. wrought-iron rifled gun weighing 12 tons, with a charge of 30 lbs.

306.



307



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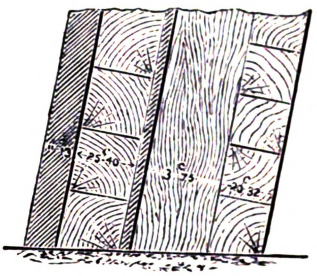
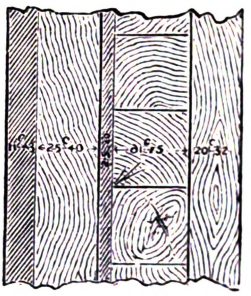
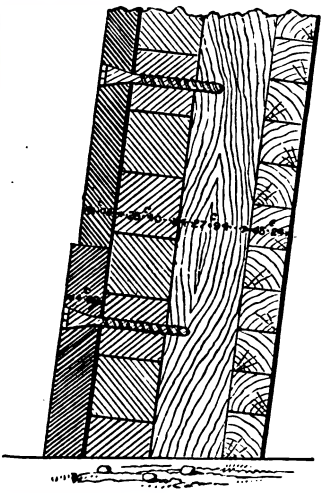


309.



310.



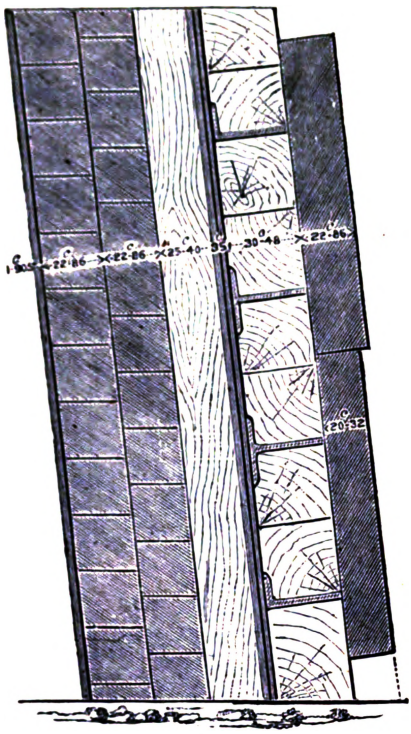
311.

A spherical steel shot weighing 73·80 lbs., fired from the 68-pounder smooth-bore with a charge of 16 lbs., penetrated the armour, driving the piece into the backing, and making an indent of 5·7 in.

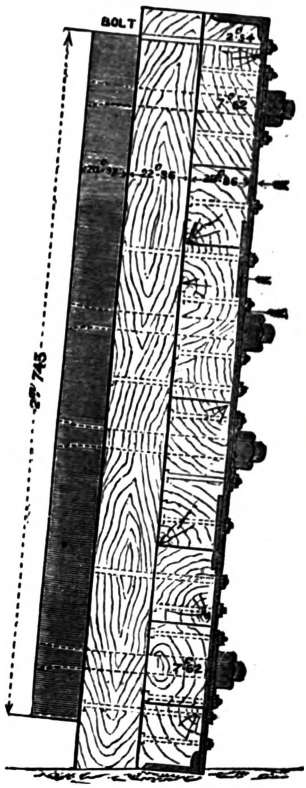
Figs. 312 and 313 show a target representing the construction of the armour of the 'Hercules.' The upper half of this structure is faced with a wrought-iron plate 9 in. thick, and the lower half with a similar plate 8 in. thick. These plates are backed with 12 in. of teak, resting against a skin of two ¾-in. plates. The whole is secured to iron ribs, 10 in. deep, with vertical teak timber worked in between them. Behind these ribs are two linings of horizontal teak timber 18 in deep, confined by 7-in. iron ribs inside all, and an inside iron skin. The armour-plates are secured by 3-in. bolts. The total thickness of the target, exclusive of the 7-in. ribs, is at the top 51¼ in., and at the bottom 47¼ in. A 13-in. muzzle-loading rifled gun, of 23 tons, with a charge of 100 lbs., and an ogival-headed chilled shot weighing 577·5 lbs., struck the 8-in. plate, and passed through the target. Another shot, weighing 580·5 lbs., from the same gun, with a similar charge, struck

the 8-in. plate, and penetrated the target to a depth of 22 in. No shot appears to have penetrated the 9-in. plate, the greatest effect being an indent of 8 27 in. in the plate.

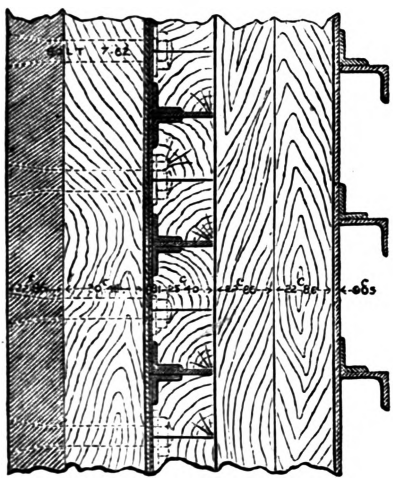
312



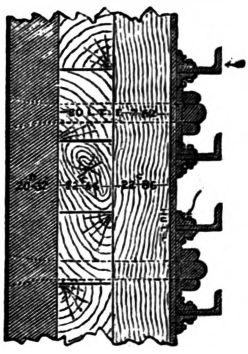
314.




313.



315.



Figs. 314 and 315 show a section and plan of the so-called 8-in. shield, constructed to test the effect of different kinds of projectiles made of steel or of chilled cast-iron. This target was constructed of 8-in. armour-plate, backed by 18 in. of teak and a ¾-in. iron skin, secured to iron ribs 12 in. apart. The object of this experiment was to obtain a shield sufficiently strong to resist or keep out steel projectiles of 250 lbs., fired at 200 yds. from the 9-in. muzzle-loading rifled gun with 43 lbs. of powder, the head of the projectile being ogival, struck with a radius of one diameter.

The results of the experiments upon this target were, that it was proof against all projectiles when fired at obliquely; that it was not penetrated when fired at direct, except by the Palliser chilled projectile, which completely pierced the target. They proved that a pointed projectile 7·92 in. diameter can cut a hole in an 8-in. plate, provided it strike with the necessary work.

*Laminated Armour.*—Laminated armour consists of a number of thin plates bolted together, so as to form a shield of a certain total thickness, which depends on the number and individual thicknesses of the plates employed. This description of iron-plating has been extensively used in America, on account of its cheapness and facility of construction; it, however, offers much less resistance to shot than solid plating, at any rate while placed in close superposition.

For experiments on this subject the targets were composed as follows:—

No. 1 Target consisted of seven $\frac{5}{8}$-in. wrought-iron plates, all breaking joint, faced with a 1·5 in. wrought-iron plate, the whole fastened together by $1\frac{1}{2}$-in. rivets and screws, 8 in. apart.

The target measured 12 ft. × 9 ft. × 6 in., and was fixed to an upright wooden frame.

No. 2 Target was composed of thirteen $\frac{5}{8}$-in. plates, faced with a 2-in. plate, and secured and supported in a similar manner to No. 1. The target measured 12 ft. × 9 ft. × $10\frac{1}{8}$ in.

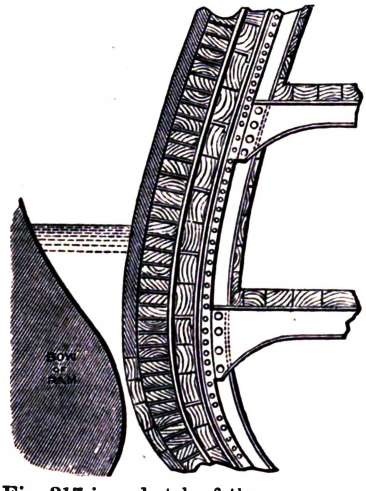
TABLE F.—SHOWING THE EFFECTS OF FIRE AGAINST LAMINATED ARMOUR.

| Photographic No. of Round. | Target. | Gun. | Charge. Weight. | Charge. Brand of Powder. | Projectile. Nature and Length. | Projectile. Weight. | Projectile. Diameter. | Striking Velocity. | $Wv^2$ in Foot $2g$ Tons on Impact. | Foot Tons per Inch of Shot's Circumference. | Observed Effects. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | lbs. | | | lbs. | in. | feet. | | | |
| Not taken | No. 1 target, laminated plates; total thickness 6 in. | 40-pr. B. L. rifled. | 5 | Rifle L. G. | Elongated cast-iron. | 41 1 | 4·7 | 1157 | 381·5 | 25·8 | Indent 2·35 in.; plate in rear considerably bulged and cracked. |
| ,, | ,, | 7-inch B. L. rifled. | 14 | ,, | ,, | 110 | 6·9 | 1140 | 991 | 45·7 | Clean through target, making a hole 13 × 13·5 in. in front plate, and sending a shower of splinters to the rear; back much torn. |
| ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | As before. |
| ,, | ,, | 68-pr. S. B. | 16 | L. G. | Spherical cast-iron. | 66·5 | 7 91 | 1380 | 878 | 35·3 | As before. |
| ,, | No. 2 target, laminated plates; total thickness $10\frac{1}{8}$ in. | 40-pr. B. L. rifled. | 5 | Rifle L. G. | Elongated cast-iron. | 41·1 | 4·7 | 1157 | 381 5 | 25·8 | Indent 1·2 in.; slight bulge in rear. |
| ,, | ,, | 7-inch B L. rifled. | 14 | ,, | ,, | 110·0 | 6·9 | 1140 | 991 | 45·7 | Indent 2·35 in.; rear of plates cracked and bulged. |
| ,, | ,, | 68-pr. S. B. | 16 | L. G. | Spherical cast-iron. | 66·5 | 7·91 | 1380 | 878 | 35·3 | Indent 3·15 in.; as before. |
| ,, | ,, | ,, | ,, | ,, | ,, | . | . | ,, | ,, | ,, | Indent 3 in.; as before. |

From these results it appears that laminated armour is considerably weaker than solid armour. Thus a 4-in solid plate would have effectually stopped all the projectiles, whereas they easily penetrated 6 in. of laminated plates.

Fig. 316 represents Chalmers' system of armour-plating. A target upon this system, which had a $3\frac{3}{4}$-in. armour-plate, a compound backing, a second plate and a cushion, with stringers running at right angles to the ship's frames, between the second plate and the skin, the stringers being riveted to the latter, when fired at with steel and cast-iron projectiles from the following guns,—68-pounder smooth-bore, with cast-iron shot and shell, 16 lbs. charge; 100-pounder Armstrong, with cast-iron shot and shell, 12 and 14 lbs. charges; 300-pounder Armstrong, with cast-iron spherical shot, 50 lb. charge; and lastly, with solid steel shot, 301 lbs., from a 300-pounder Armstrong, with 45 lbs. charge,—proved that this system of backing affords great support to the armour-plates, and prevents their distortion from buckling. It is also of considerable advantage in adding strength and resisting power to the structure, and no other target designed for naval purposes has resisted so great a weight of shot with so little injury.

316.



317.

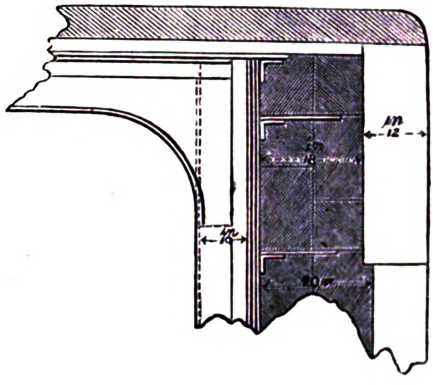
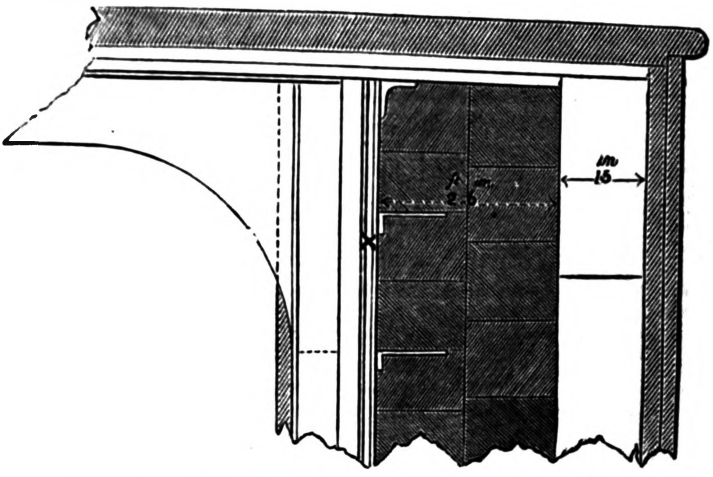



Fig. 317 is a sketch of the armour applied to the vessel 'Glatton.' It consists of 12-in. plates backed by 18 to 20 in. of teak upon an iron skin 2 in. thick.

The armour used in vessels of the large 'Monitor' type is shown in Fig. 318, and is formed of 15-in. plates, backed by 2 ft. 6 in. of teak upon two iron skins, shown at ×, each 1 in. in thickness.

318.




*Cast-iron Projectiles as compared with Steel of the same Size and Form.*—The difference between the effects of cast-iron and steel shot upon armour-plates is most marked. The latter material is the nearest approach to perfect hardness and cohesion at present in use, and the amount of *work* expended on the shot is less with steel than any other known material. With ordinary cast-iron, a large amount of *work* is expended in breaking up the projectile and hurling the fragments in all directions; but when steel shot are manufactured in the best manner, little *work* is expended on the projectile; and in one instance a 12-pounder Whitworth steel shot was of such perfect material, that after passing through 2½ in. of solid iron its temperature was apparently unaltered. Several experiments have been made with a view of ascertaining the amount of *work* lost by the breaking up of cast-iron, alteration of form in steel shot, and so on.

The following Table shows the absolute thickness of plate which can be penetrated by cast-iron shot fired from various guns with service-charges. The guns were at a distance of 100 yds. from the plates, with the exception of the 68-pounder, which was at 200 yds.

TABLE G.

| Target. | Gun. | Charge. | | Projectile. | | | Striking Velocity. | $\frac{W v^2}{2g}$ in Foot Tons on Impact. | Foot Tons per Inch of Shot's Circumference. | Observed Effects. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Weight. | Brand of Powder. | Nature and Length. | Weight. | Diameter. | | | | |
| | | lbs. | | | lbs. | in. | feet. | | | |
| Unbacked plates, 1·286 | 6-pr. B. L. rifled gun. | 0·75 | Rifle L. G. | Elongated cast-iron shot. | 6·25 | 2·50 | 1010 | 44·21 | 5·63 | Just penetrated through the plate. |
| 1·803 | 12-pr. ,, | 1·50 | ,, | ,, | 11·56 | 3·00 | 1140 | 104·1 | 11·05 | As before. |
| 2·350 | 20-pr. ,, | 3·13 | ,, | ,, | 24·81 | 3·75 | 1120 | 215·8 | 18·32 | As before. |
| 2·820 | 40-pr. ,, | 5·00 | ,, | ,, | 41·20 | 4·75 | 1150 | 377·8 | 25·32 | As before. |
| 3·85 | 68-pr. smooth-bore. | 16 | L. G. | Spherical cast-iron shot. | 66·50 | 7·91 | 1380 | 878 | 35·3 | As before. |

If the results given by this Table are compared with the effect of steel projectiles, it will appear that the cast-iron shot requires about 2½ times the *work* of the steel shot to effect the same penetration, except when the velocity of the cast-iron shot is high.

Here observe that the distance of the 68-pounder was double that of the other guns, and that being a cast-iron 68-pounder, it was fired with a weak charge compared to what it would have stood had it been a modern smooth-bored wrought-iron gun, in which case the charge should have been 24 lbs., the velocity 1700 ft. per second at 100 yards' range.

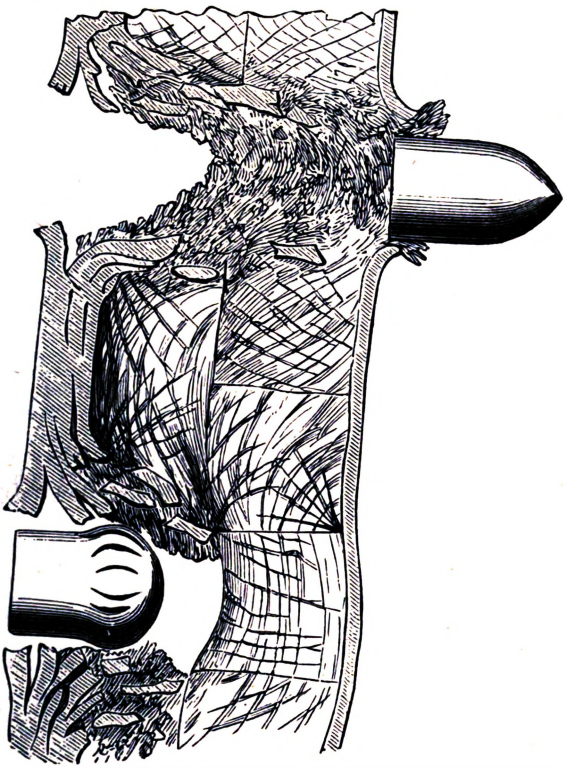
TABLE H.—SHOWING THE DIFFERENCE BETWEEN THE EFFECTS PRODUCED BY CAST-IRON AND STEEL SHOT WHEN FIRED AT IRON PLATES.

| Thickness of Plate. | Foot Tons per Inch of Shot's Circumference required for absolute Penetration. | | Difference. | Proportional Excess for Cast-iron Shot. | Remarks. |
|---|---|---|---|---|---|
| | Cast-iron Shot. | Steel Shot. | | | |
| inches. | | | | | |
| 1·286 | 5·63 | 2·29 | 3·34 | 2·517 | From results with— 6-pr. B. L. rifled gun. |
| 1·803 | 11·05 | 4·49 | 6·56 | 2·461 | 12-pr. ,, ,, |
| 2·350 | 18·32 | 7·64 | 10·68 | 2·398 | 20-pr. ,, ,, |
| 2·820 | 25·32 | 11·00 | 14·32 | 2·302 | 40-pr. ,, ,, |
| 3·850 | 35·30 | 20·50 | 14·80 | 1·722 | 68-pr. smooth-bore. |

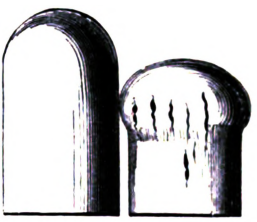
It will be seen that it is almost useless to fire cast-iron projectiles against iron defences, if *penetration* is required. As steel is a most expensive material for shot, and it has been proved that chilled iron is almost as good as steel, chilled iron will most probably be the generally used material for projectiles for battering purposes.

The proper form of front or head to be given to hardened projectiles has been a matter of much dispute. It has been found in practice, however, that the pointed form is the best. The flat-headed or round-headed shot punches out a piece of the armour-plate, Figs. 319, 320, and drives it into the backing; the shot has no means of ridding itself of this piece of armour-plate, *and has to push it in front of it through the backing*. Thus in targets penetrated by flat-headed or round-headed shot it has always been found that *the piece of armour-plate has passed through the target along with the shot*.

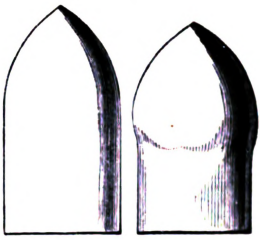
319.



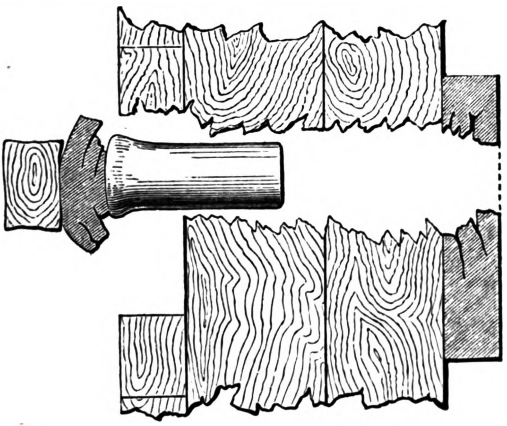
321.



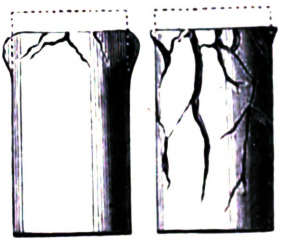
322.



320.



323.



There is another disadvantage which the blunt-headed form labours under—the tendency to set up or bulge at the head; and this result is often very marked. A pointed head, on the contrary, does not "set up" to anything like the same extent; and almost all those which have been fired have preserved their points intact after passing through the plates, see Figs. 321, 322, 323. When, however, the shot is of the form of a pointed ogival, the results of its action are far different. This projectile cuts through the armour-plate, or rather tears through, and the plate is bent back, and forced into the backing round the edge of the hole; the shot thus passes through the backing without carrying any jagged armour in front of it. Fig. 319.

The following Table K, gives the results of some late experiments, which clearly show the great superiority of the pointed head.

In these experiments both steel shot and Palliser's chilled shot and shell were used. All the projectiles were fired from the same gun, under the same circumstances, the velocity of each round being observed. The targets consisted of a structure representing the side of an iron-clad vessel, protected by solid plates of 6 in. thickness, backed by 18 in. of teak, an iron skin of two ½-in. plates, the usual iron ribs, &c. &c. A second target, of unbacked 4·5-in. plates, inclined at an angle of 38° with the ground, was erected at the same distance.

The projectiles were of a mean weight of 115 lbs., and of the following forms of head:—

*For Palliser's Chilled Shot.*

1. Ogival head, struck with a radius of one diameter, and brought to a point.
2. Belgian form, head struck with a radius of 1·47 diameter, and pointed in the shape of a cone.
3. Elliptical, the height of the ellipse being equal to the diameter of the projectile.

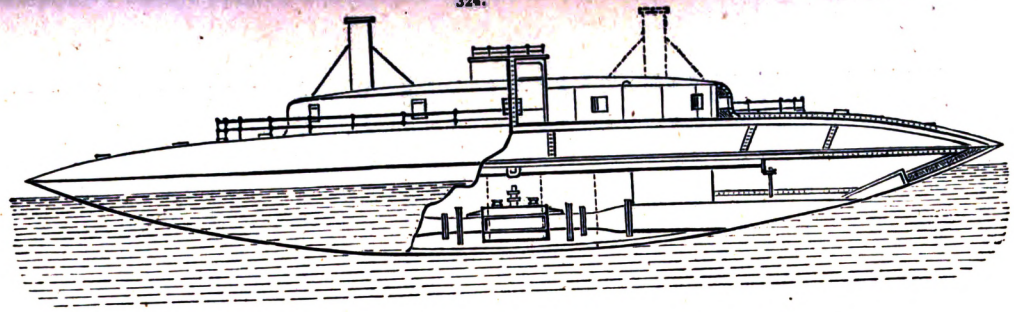
*For Steel Shot.*

1. Hemispherical.
2. Ogival head, struck with a radius of one diameter, and brought to a point.

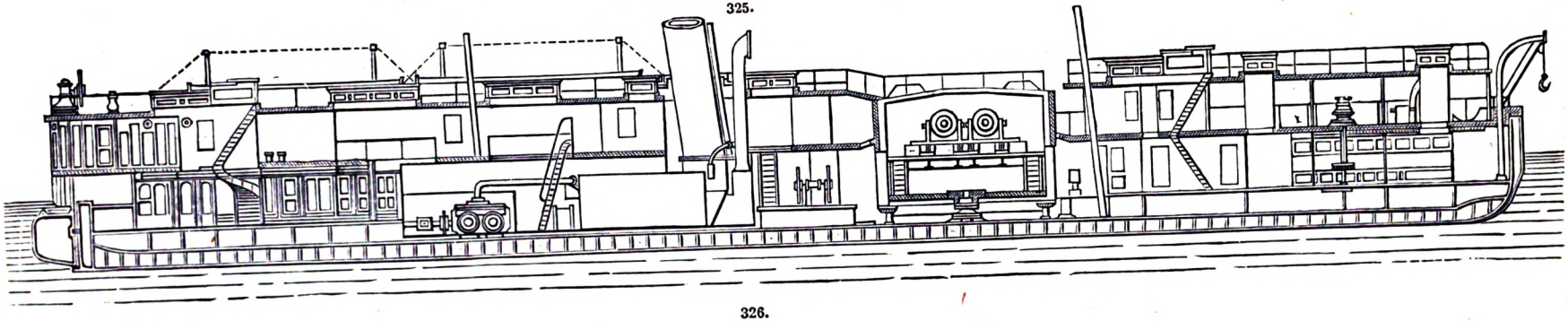
TABLE K.

| Photographic No. of Round. | Target. | Gun. | Charge. Weight. | Charge. Brand of Powder. | Projectile. Nature and Length. | Projectile. Weight. | Projectile. Diameter. | Striking Velocity. | $\frac{W v^2}{2g}$ in Foot Tons on Impact. | Foot Tons per Inch of Shot's Circumference. | Observed Effects. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | lbs. | | | lbs. | in. | feet. | | | |
| 1186 | Box target, 6-in. plates on 18 in. of teak, and a skin of two ½-in. plates, ribs, &c. No. 27. | 7-in. M. L. rifled gun of 130 cwt. | 22 | Rifle L. G. | Chilled shot, E., 13·62 in. | 117·0 | 6·9 | 1328·5 | 1432·0 | 66·06 | Struck fair between two ribs; penetrated armour-plate, and stuck in backing. Shot broke up and remained in the hole; indent 15 in. |
| 1190 | ,, | ,, | ,, | ,, | ,, | 116·5 | ,, | 1331·4 | ,, | ,, | Struck near 1186 between two ribs. Shot penetrated to inner skin, which it bulged slightly; shot remained broken up in the hole. |
| 1191 | ,, | ,, | ,, | ,, | Chilled shot, Belgian head, 14·79 in. | ,, | ,, | ,, | ,, | ,, | Struck fair between two ribs; *penetrated* the target completely. Shot broke to pieces; skin of target was here only half-inch. |
| 1192 | ,, | ,, | ,, | ,, | Chilled shot, Ogival head, 13·86 in. | 115·0 | ,, | 1340·0 | ,, | ,, | Struck partly on a rib and armour-plate bolt; *penetrated* the target completely. Shot broke to pieces. |
| 1196 | ,, | ,, | ,, | ,, | ,, | 116·25 | ,, | 1332·8 | ,, | ,, | Struck fair between two ribs; *penetrated* the target completely. Shot broke to pieces. |
| 1189 | ,, | ,, | ,, | ,, | Steel, Ogival head, 13·25 in. | 115·5 | 6·92 | 1360·0 | 1481·4 | 68·14 | Struck fair between two ribs; *penetrated* the target completely. Shot picked up inside whole, having rebounded off armour-plate at rear of box. |
| 1198 | ,, | ,, | ,, | ,, | Hemispherical-headed steel shot, 12·0 in. | 115·0 | 6·92 | 1380·0 | 1518·6 | 69·85 | Struck on rib. Shot penetrated plate, and lodged in the backing; total indent about 18 in.; rib at back cracked, and forced back slightly. |
| 1201 | ,, | ,, | ,, | ,, | ,, | ,, | ,, | 1371·0 | 1498·9 | 68 95 | Struck fair between two ribs. Shot penetrated the plate, and lodged in the backing; total indent about 14·5 in. |
| 1175 | 4·5-in. unbacked plates, inclined at an angle of 38° with the ground. | ,, | ,, | ,, | Chilled, Belgian head, 14·79 in. | 115·0 | 6·9 | 1339 | 1432·0 | 66·06 | Struck fair; made a jagged hole 1 ft. long, and a small hole through the plate. Shot broke into pieces. |
| 1202 | ,, | ,, | ,, | ,, | Chilled shell, Ogival head, 15·6 in. | 115·5 | ,, | 1349 | 1457·4 | 67·23 | Struck fair between two ribs; *penetrated* the target, bursting and setting fire to the backing. |
| 1205 | ,, | ,, | ,, | ,, | ,, | 115·0 | ,, | 1346 | 1444·7 | 66 65 | Struck full on a rib; burst in the backing; rib broken, and inner skin bulged and cracked. |
| 1176 | ,, | ,, | ,, | ,, | Chilled, Ogival head, 13·86 in. | 115·19 | ,, | 1339 | 1432·0 | 66·06 | Struck fair; *penetrated* the plate. Shot broke to pieces. |
| 1178 | ,, | ,, | ,, | ,, | ,, | 113·0 | ,, | 1372 | 1475·0 | 68·04 | Struck fair; *penetrated* the plate. Shot broke into pieces. |
| 1180 | ,, | ,, | 16 | ,, | ,, | 113·5 | 6·9 | 1253 | 1235·6 | 57·00 | Struck top of plate, scooping out a hole 4½ in. deep. Shot broke to pieces. |
| 1183 | ,, | ,, | ,, | ,, | Steel, Ogival head, 13·25 in. | 114·0 | 6·92 | 1240 | 1215·4 | 55·91 | Struck on edge of former hit; scooped out a piece of plate, and glanced off. Shot broke. |
| 1184 | ,, | ,, | ,, | ,, | Chilled, Ogival head, 13·86 in. | 114·0 | 6·9 | 1277 | 1289·0 | 59·47 | Struck fair; scooped a hole 11 × 6¼ in., and about 2 in. deep. Shot broke to pieces. |

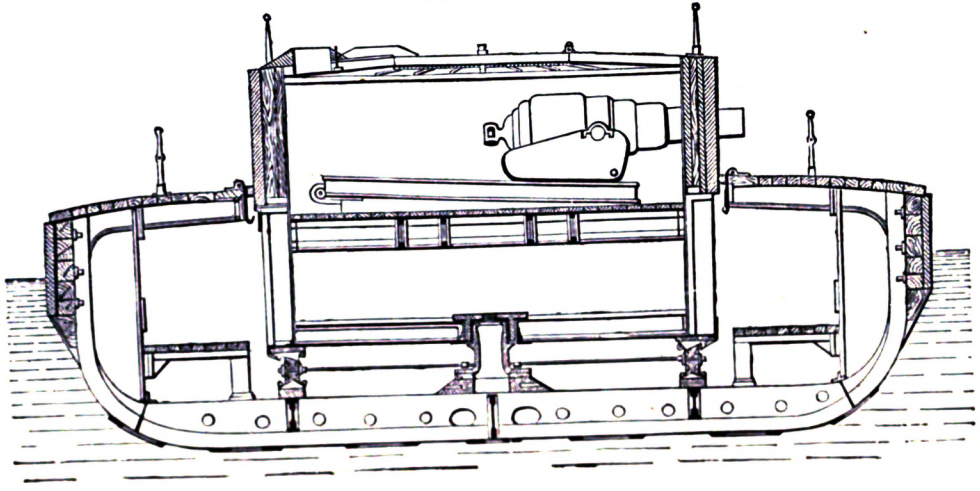
324.



325.



326.



The experiments against iron-plated targets seem to demonstrate the superiority of elongated over spherical projectiles, when the shot or shell are made of a hardened material.

The principal objections to the spherical, as compared with the elongated form, may be enumerated as follows:—The form is ill adapted for penetration, either in the case of steel or chilled iron projectiles, which require a pointed cylindrical form to develop their full power. The diameter being larger in proportion to the weight, the projectile experiences a greater resistance, both from the air in its flight and from the plate on its impact. The range and accuracy is considerably inferior. The capacity of the projectile, as a shell, is much less. Elongated projectiles have been found to be less liable to alter their shape on impact; and the cylindrical form is much better adapted for steel or chilled shells, which, as spherical, would be almost worthless.

But it is to be remembered that neither has the target been fully worked out as a scientific application of strength, nor have any satisfactory experiments been made as to the effects of a different mode of attack—that is, that which would rack in the fullest degree, by simultaneous blows—against the present system of penetration by separate shot. And this is the more important, since no great naval battle has been decided except at close quarters, where range and accuracy are thrown aside, and the victory belongs to those who hit hardest at short ranges with whole broadsides delivered at once. Here the superior velocity obtainable in all cases with spherical shot, up to 800 yds., would not fail to give more work, particularly if one-third of the shot's weight of powder be used as a battering-charge, which may well be done in modern guns. See ARTILLERY.

It should be taken into account, that if armour-plate be driven in or penetrated at short ranges by even spherical shot, shell effects follow,—the pieces of armour-plate, nuts, splinters, &c., doing all that could be expected from any shell; and that at long ranges all shot will strike at an angle with the horizontal, and any shot may strike the deck or masts even more probably than the armour-plate. The most complete armour and the cheapest that a ship can have is the power of sinking, so as to expose but little of her hull out of water.

Figs. 324, 325, 326, represent the construction of the 'Buffalo' and the 'Tiger,' ships recently built for the Dutch Government; the former being a *ram* and *monitor* combined, and the latter a *monitor*. The dimensions of the 'Buffalo' are:—breadth 40 ft., length 205 ft., depth 24 ft., tonnage 1472, load-draught 15 ft. 6 in. The dimensions of the 'Tiger' are:—breadth 44 ft., length 187 ft., and depth 11 ft. 6 in. Both vessels carry turrets of the same construction and dimensions, 6 ft. above the upper deck, and 22 ft. in diameter; pierced for two guns, and fixed upon a circular platform upon the main deck. This platform is moved by means of machinery similar to a railway turn-table, and can make one revolution in 45 seconds. The wall of the turret consists of 8-in. plates of malleable iron, 12 in. of teak, and 1-in. plates of wrought iron, making a total thickness of 21 in. Each of the 8-in. plates is 14½ ft. by 3 ft., and forms one-fifth of the circle. There are ten of these plates in each turret; they are secured to teak-backing by nut and screw bolts with "elastic cup-washers." In the 'Buffalo,' Fig. 324, a low wall rises out of the deck: it is of the same composition and thickness as the turret, the bottom of which it surrounds, and which, as well as the turning machinery, it protects. The outer skin of the vessel, for about 100 ft. amidships, is composed of 6-in. armour-plates, tapering off to 4½ in. forward and 3 in. aft, laid on 10 in. of teak amidships, tapering off at each end to 8 in.

*Works relating to Armour*:—'Report of the Secretary of the Navy on Armoured Vessels,' Washington, 1864. Norton and Valentine, 'Report on the Munitions of War at the Paris Exhibition,' royal 8vo, 1868. Dislère Note, 'Sur la Marine des États-Unis,' 8vo, Paris, 1867. Captain Noble's 'Report on the Penetration, &c., of Armour Plates,' fol., 1866.

See also:—Humber's 'Record of Modern Engineering,' fol., 1863. 'Revue Maritime et Coloniale.' 'Journal of the Royal United Service Institute.'

ARRASTRE, *in Gold-mining.*

ARRASTRE. FR., *Moulin à mulet mexicain*; GER., *Mexicanische Quartz Mühle*; ITAL., *Aia da quarzo*; SPAN., *Arrastre.*

The arrastre consists of a circular pavement of stone, about 12 ft. in diameter, on which the quartz is ground by means of two or more large stones, or mullers, dragged continually over its surface, either by horses or mules, but more frequently by the latter. The periphery of the circular pavement is surrounded by a rough kerbing of wood or flat stones, forming a kind of tub about 2 ft. in depth, and in its centre is a stout wooden post, firmly bedded in the ground, and standing nearly level with the exterior kerbing. Working on an iron pivot in this central post is a strong upright wooden shaft, secured at its upper extremity to a horizontal beam by another journal, which is often merely a prolongation of the shaft itself. This upright shaft is crossed at right angles by two strong pieces of wood, forming four arms, of which one is made sufficiently long to admit of attaching two mules for working the machine. The grinding is performed by four large blocks of hard stone, usually porphyry or granite, attached to the arms either by chains or thongs of raw hide, in such a way that their edges, in the direction of their motion, are raised about an inch from the stone pavement, whilst the other side trails upon it. These stones each weigh from 300 to 400 lbs., and in some arrastres two only are employed, in which case a single mule is sufficient to work the machine.

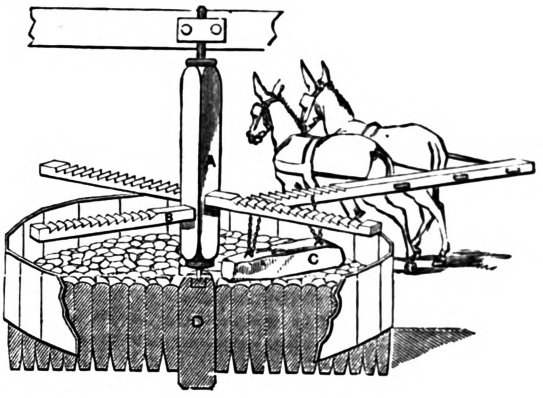
Fig. 327 is a sectional view of a Mexican arrastre, in which A is the upright shaft; B, arms to which mullers, C, are attached; and D, the central block of wood in which the lower bearing works.

Some of the arrastres used by Mexican gold miners, and for the purpose of testing the value of quartz veins, are very rudely put together, the bottom being made of unhewn flat stones laid down in clay; but in a well-constructed arrastre, intended to be permanently employed, the stones are carefully dressed and closely jointed, and, after being placed in their respective positions, are grouted in with hydraulic cement.

The charge for an ordinary arrastre is 450 lbs. of quartz, previously broken into pieces of

about the size of pigeons' eggs. The machine is now set in motion, a little water being from time to time added, and at the expiration of from four to five hours the quartz has become reduced to a finely-divided state, and more water is added, until the contents of the arrastre assume the consistency of tolerably thick cream. Quicksilver is then sprinkled over its surface to the amount of 1½ oz. for every ounce of gold supposed to be contained in the finely-divided rock which is generally known, with a considerable degree of accuracy, from the results obtained from previous charges. The grinding is after this continued for another two hours, during which time the mercury is divided into minute globules, and becomes disseminated throughout the mass, which should be of such a consistency as not to allow it to sink to the bottom, but be so held in suspension as to meet, and amalgamate with, all the particles of gold. At the expiration of this time the amalgamation is considered complete, and the process of settling the amalgam from the ground silicious matter is commenced. Water is now let into the paste so as to render it very thin, and perfectly mobile, the mules being driven very slowly, in order to allow the particles of gold and amalgam to yield to the influence of their densities, and to sink to the bottom. After having in this way slowly agitated the mixture for about half-an-hour, the thin mud is allowed to run off, leaving behind it, in the bottom of the arrastre, the gold combined with mercury in the form of amalgam. Another charge of broken quartz is now put in, and the operation is repeated, time after time, until it is thought desirable to stop for the purpose of cleaning up. In the roughly-constructed arrastre, having a bottom of uncut stones laid in clay, the run is seldom less than ten days, and is sometimes extended to three weeks or a month. In this case the amalgam settles in the crevices between the paving-stones, which have to be dug up, and all the sand and mud between them carefully washed. If, however, the machine be well constructed, and provided with a closely-paved bottom, the cleaning up is more frequently repeated, since the quicksilver and amalgam do not find their way so readily between the stones, but remain on the surface, from which they are easily collected in an iron vessel, for subsequent treatment by straining and retorting.

327.



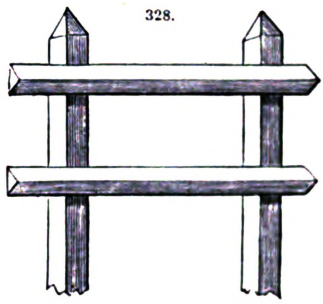

The arrastre does its work slowly, and consumes a large amount of power in proportion to the quantity of rock crushed, but is an excellent amalgamator, and is often valuable for the purpose of testing newly-discovered veins, and ascertaining their approximate yield. It is also the arrangement most commonly adopted by a miner, who, having found a rich pocket in his vein, is desirous of converting a portion of it into money, and of ascertaining whether it be likely to continue productive, before incurring the expense of erecting more costly and complicated apparatus. A modification of the arrastre is not unfrequently employed for the treatment of pyrites separated from tailings by washing, and is generally considered to be well adapted for that purpose.

**ARRIS.** Fr., *Arête;* Ger., *Kante;* Ital., *Spigolo, Risega;* Span., *Vivo, arista.*

The angle formed by the meeting of two surfaces which are not in the same plane. In builders' work any angle which retains its original sharpness. With workmen the term "arris" has only one dimension, that of length, in which it differs from the word "edge," which usually has two dimensions, namely, length and thickness. The junction of two sides of a square stone is called its *arris*, but the side of least dimensions of a board or a stone slab is called its *edge*.

**ARRIS FILLET.** Fr., *Nervure angulaire;* Ger., *Scharfkantiger Vorsprung;* Ital., *Corrente triangolare;* Span., *Filete de arista.*

328.



An arris fillet is a slight piece of timber, triangular in section, used to raise the slates on a roof where they are cut by a chimney-shaft, skylight, or wall, when it cuts the slates obliquely; the object being to throw off the wet which would otherwise find its way under the flashing. See Fillet.

**ARRIS GUTTER.** Fr., *Gouttière angulaire;* Ger., *Scharfkantige Dachrinne;* Ital., *Gorna a* V; Span., *Gotera de forma* V.

An arris gutter is a gutter formed to a V-shape, usually of wood, and fixed to the eaves of a building.

**ARRIS RAIL.** Fr., *Ornière angulaire;* Ger., *Kantenschiene;* Ital., *Regolo triangolare;* Span., *Rail de forma* V.

An *arris rail*, in carpentry, is a rail cut to a triangular section, and when fixed to posts, as Fig. 328, shows the arris in front with an oblique surface on each side. A flat rail, or one with a rectangular section, would be called a *riband*, if used in a palisade.

329

**ARRIS-WISE.** Fr., *En Diagonale;* Ger., *Eckweise;* Ital., *A sbieco;* Span., *Diagonalmente.*

A balk or piece of squared timber sawn diagonally, Fig. 329, is said to be cut "arris-wise."

In bricklayers' work, tiles laid diagonally.

ARSENIC. Fr., *Arsenic*; Ger., *Arsenik*; Ital., *Arsenico*; Span., *Arsénico*.

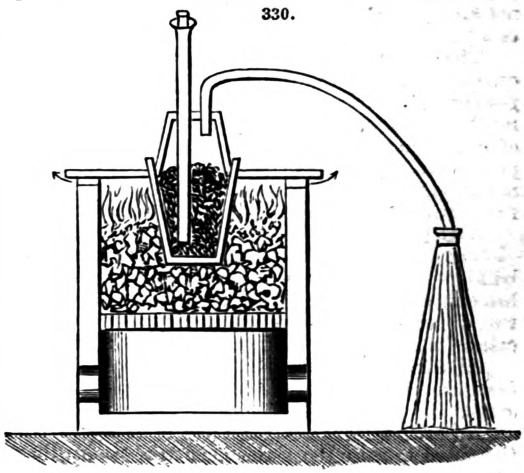
Arsenic is a metal of a steel-grey colour, and brilliant lustre, though usually dull from tarnish. This metal is usually obtained from arsenious acid, and the latter by calcination from native arseniurets, such as those of iron, copper, and other metals. Hence it is, in most cases, a secondary product. Yet much of the arsenious acid of commerce is manufactured from iron pyrites, which, when the arsenic is extracted, serves no other purpose. Arsenic enters as an important agent into many branches of art, and is a useful metal in forming fusible alloys.

The metal arsenic is not poisonous, but one of its oxides (arsenious acid), formed by its combustion in air, is extremely so; and in operating either with the metal or the acid some caution is required on the part of the operator. When arsenious acid is operated on, if we moisten it, the inhalation of the dust is prevented. And when an alloy of arsenic is melted and operated on, the vapours of the metal are made harmless when the operator fills his mouth with grains of charcoal, renewing them from time to time. This charcoal will absorb any arsenic which may accidentally enter the organs of respiration. Arsenical pyrites is the common ore of this metal. It is here combined with iron, silver, gold, bismuth, and antimony. In all cases of its application in practice, we may consider the arsenious acid as the only ore; and as this is obtained as a secondary product in the calcination of cobalt ores, we shall include the description of its manufacture in the article on that substance.

The arsenious acid of commerce is white, glassy when fresh, but generally opaque when brought into market for sale. For metallurgical purposes no arsenious acid in powder ought to be used, for it is frequently adulterated with gypsum or other matter. The commercial article is always more or less perfectly glassy or milky, or transparent in the interior of the flat pieces, while on the exterior it appears opaque; it is generally vitreous throughout its whole mass. It is slightly soluble in water. About ten parts may be dissolved in boiling water: this quantity, however, depends on the amount of acid present. Water never dissolves the whole of it, even when less than the above quantity is exposed to its action; it will dissolve more when a large quantity of acid is afforded. Arsenious acid consists of 75·8 metal, and 24·19 oxygen. It sublimes in open vessels at 380°; it is decomposed by hydrogen, carbon, sulphur, phosphorus, and some metals, such as lead, iron, silver, &c.

The metal arsenic is easily obtained pure when arsenious acid is mixed with fatty oil, or a compound of carbon and hydrogen, or finely-pulverized soft charcoal, and heated gently in a glass tube. It evaporates at 356°, and is therefore easily smelted, and the metal condenses in the cold parts of the heated tube. In large quantities it may be obtained by mixing arsenious acid with coarse charcoal-powder, or what is better still, *culm*—small fragments of bituminous coal—and exposing it in a large crucible to a red heat. This crucible is covered by a second one, as shown in Fig. 330, and well luted; the lower pot is exposed to a red heat, while the upper one is kept cool. The metal thus formed and evaporated will condense in the upper pot, from which it is easily separated, when cold. The same operation may be performed on arsenical pyrites, without carbon; and the metal is obtained in a similar manner. Iron, nickel, and other permanent metals remain in the lower pot, combined with some arsenic.

330.



The metal is of a high lustre, and greyish-white; its specific gravity is 5·70. Its weight and lustre increase with its purity. It evaporates without melting; and its vapours, which smell strongly of garlic, are sometimes confounded with those of phosphorus. Arsenious acid does not smell; it is the metal only which emits this odour. It is not ductile, nor malleable, and may be converted into fine powder in a mortar. It is highly combustible, and deflagrates when either mixed or heated gently with saltpetre.

If this metal, in its pure state, is of little interest to the metallurgist, its alloys are of much value. All metals, without an exception, are made more fusible by the addition of arsenic; in some instances its influence is remarkably distinct. The alkaline metals combine with it with great facility, even when it is simply heated with the oxides of those metals—such as potassa or soda. It requires extreme caution to operate on these alloys; that is, on those of the alkaline metals and arsenic, because they decompose rapidly in damp air, and evolve arseniuretted hydrogen—a virulent poison—the effect of which resists the most refined skill of the physician. In combination with lead—in shot—arsenic is harmless; and also in all compounds of the proper metals, when its quantity is not too large. Aluminum, and all the metals of this class, combine very readily with arsenic. In fact, all metals combine easily with arsenic, but they are quite as easily decomposed. The decomposition of arsenical alloys is effected by merely continued heat, and, with the exception of silver, in a short time. The higher the degree of heat is, so much shorter is the time in which the act is accomplished. When it is desirable to retain arsenic in the composition, it is necessary to melt the metals at as low a heat as possible. The combination of arsenic with other metals is as easily performed as the decomposition. Metallic arsenic and lead cannot be combined directly; but when melted lead is covered by arsenious acid, some lead is oxidized, and in its place arsenic is absorbed. In the same manner, other metals, which melt at or near the

heat at which arsenious acid volatilizes, may be combined with arsenic. Iron, chromium, copper, and others, cannot be alloyed by these means, but they may be effectually combined with arsenic in a manner described in our articles on these metals; and there is no doubt that all alloys of this kind are most safely and correctly compounded by that manner—namely, cementing the metals directly, or their oxides, with arsenious acid and carbon, at a heat at which neither the refractory metals nor the alloy is melted, and then melt the alloy thus formed at the lowest heat at which it will dissolve in a crucible, with the exclusion of oxygen; that is, under a cover of fusible glass.

Alloys of arsenic cannot be converted into vessels in which food for men or animals is prepared, but it finds extensive applications in other cases; and when its properties are more thoroughly understood, it will be still more generally used. In virtue of its property of causing the fluidity of metals, when present in small quantities, it promotes the union of those metals which, without its assistance, do not unite. Zinc and lead do not unite very readily; but with the assistance of a little arsenic, both form a firm combination. Iron has no affinity for lead, but when arsenic is present it forms an alloy with it. Thus we may form combinations which, without the assistance of arsenic, cannot so easily be accomplished. Iron and alumina may be formed by melting grey-iron and pure alumina together; in this case all the impurities of the cast iron are in the compound. When pure iron filings or turnings are cemented in alumina, arsenious acid, and carbon, and then melted in a crucible so as to expel the arsenic, an alloy of iron and aluminum of great purity is formed, which, however, contains traces of arsenic.

Arsenic, like *antimony*, has a remarkable tendency to cause metals to crystallize; but it does not make quite as brittle alloys as the latter. In producing a high degree of fluidity, it admits the melting of metals at a low heat, and consequently the formation of small crystals and fine grain, and enables the metals to contract into a small compass, which causes them to be close and to assume a high polish. With the closeness of grain, the hardness and brittleness increases.

Arsenic causes all metals to be whiter than they naturally are.

ARTESIAN WELL. Fr., *Puits artésien;* Ger., *Artesischer Brunnen;* Ital., *Pozzo artesiano;* Span., *Pozo artesiano.*

An artesian well is a shaft sunk or bored through impermeable strata, until a water-bearing stratum is tapped, when the water is forced upwards by means of the hydrostatic pressure due to the superior level at which the rain-water was received.

When comparing the operations and tools of artesian well-borers, George Rowdon Burnell, in a paper, given in the Minutes of the Institution of Civil Engineers, "On the Machinery Employed in Sinking Artesian Wells on the Continent," takes three systems, namely,—the Chinese, or Fauvelle's system; the French well-borers', or, rather, the usual well-borers' system; and Kind's system. Of these, the system of Fauvelle was at first much patronized by Arago and by Dr. Buckland, but it is now very little practised on the Continent, and not at all in Great Britain. The principles upon which it was founded were, first, that the motion given to the tool in rotation was simply derived from the resistance that a rope would oppose to an effort of torsion; and, therefore, that the limits of application of the system were only such as would provide that the tool should be safely acted upon; and, secondly, that the injection of a current of water, descending through a central tube, should wash out the detritus created by the cutting tool at the bottom. The difficulties attending the removal of the detritus were enormous; and, though the system of Fauvelle answered tolerably well when applied to shallow borings, it was found to be attended with such disadvantages when applied on a large scale, that it has been generally abandoned. The quantity of water required to keep the boring-tool clear is a great objection to the introduction of this system, especially as in the majority of cases artesian wells are sunk in such places as are deprived of the advantage of a large supply.

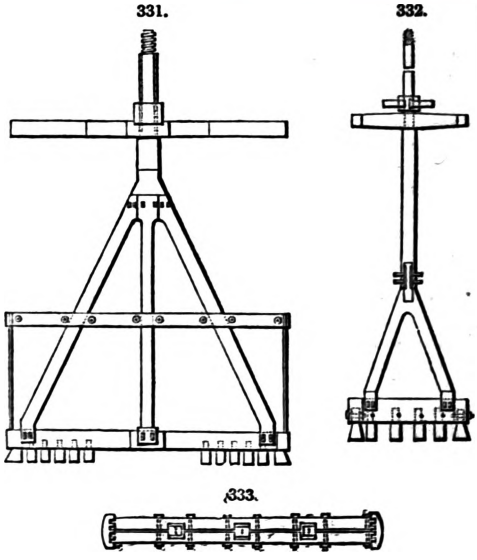
In the ordinary system of well-boring, the motion of the tools used for the comminution, or for the removal of the rocks, is effected by the use of solid iron rods, connected with the upper parts of the machinery, so that the weight of the rods, and the weight of the tools themselves, increase in proportion to the depth of the excavation. It follows from this fact, that where the excavation is very deep, there is considerable difficulty in transmitting the blow of the tool, in consequence of the vibration produced in the long rod, or in consequence of the torsion; and, for the same reason, there is a danger of the blows not being equally delivered at the bottom. It has been attempted to obviate this difficulty by the use of hollow rods, presenting greater sectional area than was absolutely necessary for the particular case, in order to increase their lateral resistance to the blows tending to produce vibration. The trepan is made so as to fall from a height of 2 feet, but the disengagement of the machinery is effected by the reaction of the column of water that the trepan works in. The majority of well-borers have, in many instances, used the hollow rods filled with cork, or with similar substances, and they have also tried the Euyenhausen joint; but they do not appear to have made so much use of Kind's system for removing the products of the excavation, and they more frequently resort to augers and chisels.

The first well that was executed of great depth, and which gave rise to the adoption of tools which directed public attention to the art of well-boring, was that for the city of Paris by Mulot, at the Abattoir of Grenelle. This was commenced in the year 1832; and, after more than eight years' incessant labour, water rose, on the 26th of February, 1842, from the total depth of 1798 feet. Subsequent to this, many wells have been sunk on the Continent, with the hope of attaining the brine springs so often met with in the Rhine provinces, or the springs destined for the supply of towns, and which are even deeper than the well of Grenelle, reaching in some cases to the extraordinary depth of 2800 feet; but all of them, like the Grenelle well, of small diameter. In their construction, however, the German engineers introduced some important modifications of the tools employed; and, amongst other inventions, Euyenhausen imparted a sliding movement to the striking part of the tool used for comminuting the rock, so as to fall always through a certain distance: and thus, while he produced a uniform action upon the rock at the bottom, he avoided the

jar of the tools. Kind also began to apply his system to the working of the large excavations for the purpose of winning coal. Whilst the art was in this state, and when he had already executed some very important works in Germany, Belgium, the North of France, Creuzot, Seraing, &c., the Municipal Council of Paris determined to intrust him with the execution of a new well they were about to sink at Passy. The well of Passy was intended to be executed in the Paris basin, which it was to traverse with a diameter, hitherto unattempted, of 1 mètre, 3 2809 ft.; that of the Grenelle well being only 20 centimetres, 8 in. It was calculated that it would reach the water-bearing stratum at nearly the same depth as the latter, and would yield 8000 mètres or 10,000 cubic mètres in 24 hours, or about 1,786,240 gallons to 2,232,800 gallons a-day.

The operations were undertaken by Kind under a contract with the Municipality of Paris, by which he bound himself to complete the works within the space of twelve months from the date of their commencement, and to deliver the above quantity of water for the sum of 300,000 francs, 12,000*l*. On the 31st of May, 1857—after the workmen had been engaged nearly the time stipulated for the completion of the work, and when the boring had been advanced to the depth of 1732 ft. from the surface—the excavation suddenly collapsed in the upper strata, at about 100 ft. from the ground, and filled up the bore. Kind would have been ruined had the engineers of the town held him to the strict letter of his contract; but it was decided to behave in a liberal manner, and to release him from it, the town retaining his services for the completion of the well, as also the right to use his patent machinery. The difficulties encountered in carrying the excavation through the clays of the upper strata were found to be so serious that, under the new arrangement, it required six years and nine months of continuous efforts to reach the water-bearing stratum, of which time the far larger portion was employed in traversing the clay beds. The upper part of this well was finally lined with solid masonry, to the depth of 150 ft. from the surface; and beyond that depth tubing of wood and iron was introduced. This tubing was continued to the depth of 1804 ft. from the surface, and had at the bottom a length of copper pipe pierced with holes to allow the water to enter. At this depth the compound tubing could not be made to descend any lower, but the engineers employed by the city of Paris were convinced that they could obtain the water by means of a preliminary boring; and therefore they proceeded to sink in the interior of the above tube of 3 2809 ft. diameter, an inner tube 2 ft. 4 in. diameter, formed of wrought-iron plates 2 in. thick, so as to enable them to traverse the clays encountered at this zone. At last, the water-bearing strata were met with on the 24th of September, 1861, at the depth of 1913 ft. 10 in. from the ground-line; the yield of the well being, at the first stroke of the tool that pierced the crust, 15,000 cubic mètres in 24 hours, or 3,349,200 gallons a-day; it quickly rose to 25,000 cubic mètres, or 5,582,000 gallons a-day; and as long as the column of water rose without any sensible diminution, it continued to deliver a uniform quantity of 17,000 mètres, or 3,795,000 gallons a-day. The total cost of this well was more than 40,000*l*., instead of 12,000*l*., at which Kind had originally estimated it.

In sinking the well of Passy, the weight of the trepan for comminuting the rock was about 1 ton 16 cwt., 1800 kilog.; the height through which it fell was about 60 centimètres; and its diameter was 3 ft. $3\frac{7}{16}$ in., 1 mètre. The rods were of oak, about 8 in. on the side, and the dimensions of the cutting tool were limited to 3 ft. $3\frac{7}{16}$ in. because it worked the whole time in water; but generally the class of borings Kind undertook were of such a description as justified resorting to tools of great dimensions. When sinking the shafts for winning coal, his operations required to be carried on with the full diameters of 10 ft. or 14 ft.; and he then drove a boring of 3 ft. 4 in. diameter in the first instance, and subsequently enlarged this excavation. There can be no objection to executing artesian borings of this diameter, other than the probable exhaustion of the supply; particularly as it is now known that the yield of water by these methods is proportionate to the diameter of the column; though, strange as it may appear, the first opposition to Kind's plan of sinking the well of Passy was founded upon the assumption that he would not meet with a larger supply of water from the sub-cretaceous formations than had been met with at Grenelle, where the diameter of the boring was at the bottom not more than 8 in. It is now, however, proved that there is a direct gain in adopting the larger borings, not only as regards the quantity of water to be derived from them, but also in their execution, arising from the fact that the tools can be made more secure against the effects of torsion or of concussion against the sides of the excavation, which is the cause of the most serious accidents met with in well-sinking.

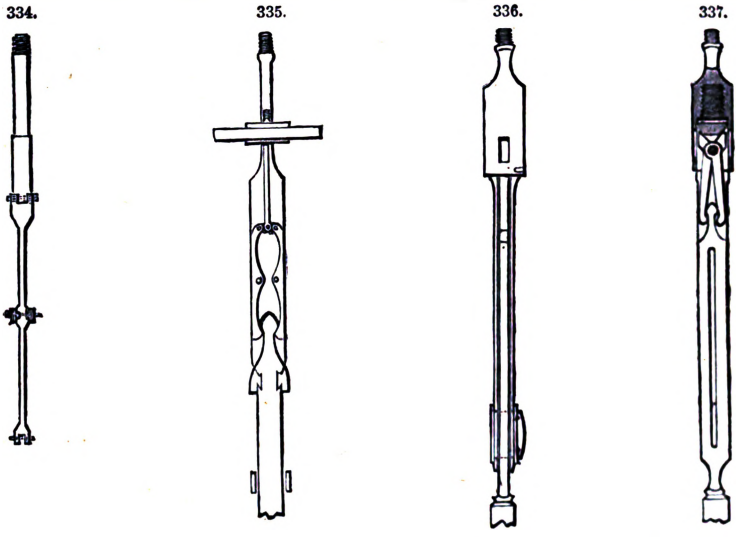



The trepan of M. Kind contains some peculiar details, which are shown in Figs. 331, 332. The trepan is composed of two principal pieces, the frame and the arms, both of wrought iron, with the exception of the teeth of the cutting part, which are of cast steel. The frame has at the bottom a series of holes, slightly conical, into which the teeth are inserted, and tightly wedged up, Fig. 333. These teeth are placed with their cutting edges on the longitudinal axis of the frame that receives them; and at the extremity of the frame there are formed two heads,

forged out of the same piece with the body of the tool, which also carries two teeth, placed in the same direction as the others, but double their width, in order to render this part of the tool more powerful. By increasing the dimensions of these end-teeth, the diameter of the boring can be augmented, so as to compensate for the diminution of the clear space caused by the tubing, necessarily introduced for security in traversing strata disposed to fall in, or for the purpose of allowing the water from below to escape at an intermediate level.

Above the lower part of the frame of the trepan is a second piece, composed of two parts bolted together, and made to support the lower portion of the frame. This part of the machinery also carries two teeth at its extremities, which serve to guide the tool in its descent, and to work off the asperities left by the lower portion of the trepan. Above this, again, are the guides of the machinery, properly speaking, consisting of two pieces of wrought iron, arranged in the form of a cross, with the ends turned up, so as to preserve the machinery perfectly vertical in its movements, by pressing against the sides of the boring already executed. These pieces are independent of the blades of the trepan, and may be moved closer to it or farther away from it, as may be desired. The stem and the arms are terminated by a single piece of wrought iron, which is joined to the frame with a kind of saddle-joint, and is kept in its place by means of keys and wedges. The whole of the trepan is finally jointed to the great rods that communicate the motion from the surface, by means of a screw-coupling, formed below the part of the tool which bears the joint; this arrangement permits the free fall of the cutting part, and unites the top of the arms and frame, and the rod, Fig. 334. It has been proposed to substitute for this screw-coupling a keyed joint, in order to avoid the inconvenience frequently found to attend the rusting of the screw, which often interposes great difficulties in cases where it becomes necessary to withdraw the trepan. Kind introduced some modifications in the trepans employed in carrying out the large borings for the coal mines in Belgium. These modifications were rendered necessary by the large dimensions he was obliged to give the borings, and by the preliminary use of a smaller trepan.

The sliding joint is the part of Euyenhausen's invention most unhesitatingly adopted by Kind, and it is one of the peculiarities of his system as contrasted with the processes formerly in use. So long as his operations were confined to the small dimensions usually adopted for artesian borings, he contented himself with making a description of joint with a free fall; a simple movement of disengagement regulating the height fixed by the machinery itself, like the fall of the monkey in a pile-driving machine; but it was found that this system did not answer when applied to large excavations, and it also presented certain dangers. Kind then, for the larger class of borings, availed himself of sliding guides, so contrived as to be equally thrown out of gear when the machinery had come to the end of the stroke, and maintained in their respective positions by being made in two pieces, of which the inner one worked upon slides, moving freely in the piece that communicated the motion to the striking part of the machinery. The two parts of the tool were connected with pins, and with a sliding joint, which, in the Passy well, was thrown out of gear by the reaction of the column of water above the tool unloosing the click that upheld the lower part of the trepan, Figs. 335, 336, 337. The changes thus made in the usual way of

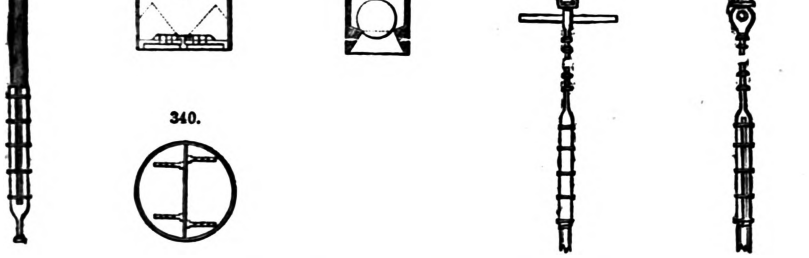



releasing the tool, and in guiding it in its fall were, however, matters of detail; they involved no new principle in the manner of well-boring; and the modern authorities upon the subject consider that there was something deficient in Kind's system of making the column of water act upon a disc by which the click was set in motion. This system, in fact, required the presence of a column of water, not always to be commanded, especially when the borings had to be executed in the carboniferous series.

The rods used for the suspension of the trepan, and for the transmission of the blows to it, were of oak; and this alone would constitute one of the most characteristic differences between the system of tools introduced by Kind and those made by the majority of well-borers, but which, like the disengagement of the tool intended to comminute the rock, depended for its success upon the boring being filled with water. The resistance that the wood offers, by its elasticity, to the

effects of any sudden jar, is also to be taken into account in the comparison of the latter with iron, for the iron is liable to change its form under the influence of this cause. The resistance to an effort of torsion need not, however, be much dwelt on, for the turn given to the trepan is always made when the tool is lifted up from its bed. For the purpose of making the rods, Kind recommended that straight-grown trees, of the requisite diameter, should be selected, rather than that they should be made of cut timber, as there is less danger of the wood warping, and the character of the wood is more homogeneous. He generally used these trees in lengths of about 50 feet, and he connected them at the ends with wrought-iron joints, fitting one into the other, Fig. 338. The ironwork of the joints is made with a shoulder underneath the screw-coupling, to allow the rods to be suspended by the ordinary *crow's-foot* during the operation of raising or lowering them. In the works executed at Passy there was a kind of frame erected over the centre of the boring, of sufficient height to allow of the rods being withdrawn in two lengths at a time, thus producing a considerable economy of time and labour.

All the processes yet introduced for removing the products of the excavation must be considered to be, more or less, defective, because all are established on the supposition that the comminuting tool must be withdrawn, in order that the spoon, or other tool intended to remove the products of the working of the comminutor, may be inserted. This remark applies to Kind's operations at Passy and elsewhere, as he removed the rock detached from the bottom of the excavation by a spoon, Figs. 339, 340, which was a modification of the tool he invariably employs for this purpose. It consisted of a cylinder of wrought iron, suspended from the rods by a frame, and fastened to it, a little below the centre of gravity, so that the operation of upsetting it, when loaded, could be easily performed. This cylinder was lowered to the level of the last workings of the trepan, and the materials already detached by that instrument were forced into the tool, by the gradual movement of the latter in a vertical direction. Some other implements, employed by Kind for the purpose of removing the products of the excavation in the shafts for the coal-mines of the North of France, were ingenious, and well adapted to the large dimensions of the shafts; but they were all, in some degree, exposed to the danger of becoming fixed, if used in the small borings of artesian wells, by the minute particles of rocks falling down between their sides and the excavation from above. Their use was therefore abandoned, and the well of Passy was cleared out with the spoon, the bottom of which was made to open upwards, with a hinged flap, which admitted the finer materials detached by the trepan. There were also several tools for the purpose of withdrawing the broken parts of the machinery from the excavation, or whatever substances might fall in from above; and all were marked by a great degree of simplicity, but they did not differ enough from those generally used by well-borers for the same purposes to merit further remarks. In fact, the accidents intended to be guarded against or remedied are so precisely alike in all cases, that there can be little variety in the manufacture of these instruments. But G. R. Burnell believed that Kind deprived himself of a valuable appliance in not using the ball-clack, *la soupape à boulet*, that other well-borers employ, Fig. 341. The tools used by Mulot, Laurent, Dru, and other French well-borers, are admirably adapted for the extraction of the materials from excavations of small diameter, but would be of no avail if applied to the well of Passy. They seem to have been designed for wells which rarely exceed the diameter of that executed at Grenelle.




At Passy, great strength was given to the head of the striking-tool, and to the part of the machinery applied to turn the trepan, because the great weight of the latter superinduced the danger of its breaking off under the influence of the shock, and because the solidity of this part of the machinery necessarily regulated the whole working of the tool. The head of the "assemblage" was connected with the balance-beam of the steam-engine by a Vaucanson chain, with a screw-coupling, admitting of being lengthened as the trepan descended, Figs. 342, 343. The balance-beam, in order to increase its elastic force in the upward stroke, is in Kind's works made of

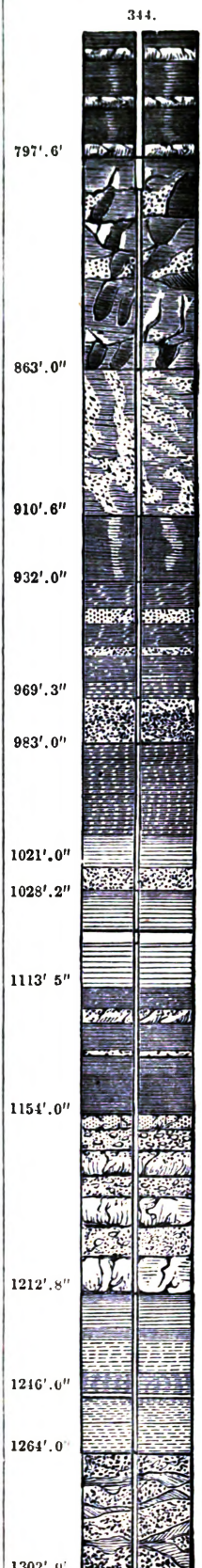
wood, in two pieces; the upper one being of fir and the lower one of beech. The whole of the machinery is put in motion by steam, which is admitted to the upper part of the cylinder, and presses it down, and thus raises the tool at the other end of the beam to that part in connection with the cylinder. The counterpoise to the weight of the tools is also placed upon the cylinder-end of the beam. The cylinder receives the steam through ports that are opened and closed by hand, like those of a Nasmyth's hammer which was invented by Robert Wilson, of Patricroft; so that the number of the strokes of the piston may be increased or diminished, and the length of the strokes may be increased, as occasion may require.

The balance-beam is continued beyond the point where the piston is connected with it, and it goes to meet the blocks placed to check the force of the blow given by the descent of the tool. The guides of the piston-head are attached to the part of the machinery that acts in this manner; but at Passy, Kind made the balance-beam work upon two free plummer-blocks, or blocks having no permanent cover, that they might be more easily moved whenever it was necessary to displace the beam, for the purpose of taking up or letting down the rods, or for changing the tools; for the balance-beam was always immediately over the centre of the tools, and it therefore had to be displaced every time that the latter were required to be changed. This was effected by allowing the beam to slide horizontally, so as to leave the mouth of the pit open. The counter-check, above mentioned, likewise prevented the piston from striking the cylinder-cover with too great a force when it was brought back by the weight of the tools to its original position. The operation of raising and lowering the rods, or of changing the tools, was performed at Passy by a separate steam-engine, and the spoon was discharged into a special truck, moving upon a railway expressly laid for this purpose in the great tower erected over the excavation. All these arrangements were in fact made with the extreme attention to the details of the various parts of the work which characterizes the proceedings of foreign engineers, and conduces so much to their success.

The beating, or comminution of the rock, was usually effected at Passy at the rate of from fifteen strokes to twenty strokes per minute. The rate of descent, of course, differed in a marked manner, according to the nature of the rock operated upon; but, generally speaking, the trepan was worked for the space of about eight hours at a time, after which it was withdrawn, and the spoon let down, in order to remove the detritus. The average number of men employed in the gang, besides the foreman, or the superintendent of the well, was about fourteen: they consisted of a smith and hammerman, whose duty it was to keep the tools in order; and two shifts of men intrusted with the excavation, namely, an engine-driver and stoker, a chief workman, or sub-foreman, and three assistants. The total time employed in sinking the shafts executed upon this system in the North of France, where it has been applied without meeting with the accidents encountered in the Passy well, was found to be susceptible of being divided in the following manner: from 25 per cent. to 56 per cent. was employed in manœuvring the trepan; from 11 per cent. to 14½ per cent. in raising and lowering the tools; from 19 per cent. to 21 per cent. in removing the materials detached from the rocks, and cleaning out the bottom of the excavation; and from 8 per cent. to 10½ per cent. was lost, owing to the stoppage of the engines, or to the accidents from broken tools, or to other causes always attending these operations. In the well of Passy there was, of course, a considerable difference in the proportions of the time employed in the various details of the work; and the long period occupied in obviating the effects of the slips which took place in the clays, both in the basement beds of the Paris basin and in the sub-cretaceous strata, would render any comparison derived from that well of little value; but it would appear that, until the great accident occurred, the various operations went on precisely as Kind had calculated upon.

The essential difference between the systems of Kind and those of the ordinary well-borers appears to consist in the use of a trepan of considerable diameter, falling through a certain height; and in the rods of oak, working in water, which were thus easily counterbalanced. All the other tools employed are in point of fact quite irrespective of the merits of the various processes. The advantages of these inventions would be very great, provided the well were sunk in such circumstances as would allow of its being worked under water, and the results of the Passy boring demonstrated that these inventions had a real existence, for the accidents attending that work were such as might have been expected in the course of boring artesian wells. It may be questioned whether the engineers of the town were justified in passing the contract with Kind to finish the work within the time, and for the sum at which he undertook it, but they certainly treated him with kindness and consideration, in allowing him to conduct the work at the expense of the city of Paris, for so long a period after the expiration of his contract. It seems, however, that the French well-borers could not at the time have attempted to continue the well upon any other system than that introduced by Kind; that is to say, upon the supposition that it should be completed of the dimensions originally undertaken. The patent has now expired, and the processes he introduced have consequently been open to the imitation of all the world, and no doubt they will be adopted by the French well-borers. Experience has shown, in fact, that this detail was badly executed at the well of Passy. The masonry lining was introduced after his contract had expired, and when he had ceased to have the control of the works, the wrought-iron tubing at the lower part of the excavation being a subsequent idea. It has followed from this defective system of tubing—the wood necessarily yielding in the vertical joints—that the water in its upward passage escaped through the joints, and went to supply the basement beds of the Paris basin, which are as much resorted to as the London sand-beds for an artesian supply; and, in fact, the level of the water has been raised in the neighbouring wells by the quantity let in from below, and the yield of the well itself has been proportionally diminished, until it has fallen to 450,000 gallons per day. That the increased yield of the neighbouring wells is to be accounted for by the escape of the water from the artesian boring is additionally proved by the temperature of the water in them; it is found to be nearly 82° Fah., or nearly that observed in the water of Passy. This was an unfortunate complication of the bargain made between Kind and the Muni-

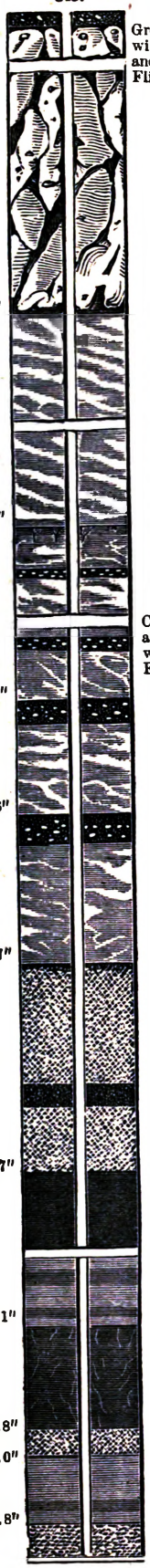
## Boring at Kentish Town, London.




## Boring at Passy, Paris.

BORING AT PASSY, PARIS—*continued.*

345.



10′.6″ — Grey Chalk, with Marl and beds of Flints.

1266′.1″

187′.2″

1453′.9″

10′.10″ — Chalk Marl, alternating with beds of Flints.

1564′.7″

35′.11″

1600′.6″

49′.1″

1649′.7″

68′.0″

1717′.7″

142′.4″ — Upper Greensand and Gault.

1859′.11″

32′.9″

1892.8″

8′.4″

1901′.0″

22′.8″

1923′.8″ — Lower Greensand.

BORING AT GRENELLE, PARIS.

346.

33′.4″ — Alluvial Earth, Sand, and beds of rolled Flints.

33′.4″

100′.6″ — Plastic Clays, with quartzose Sands.

133′.10″

16′.19″ — Calcareous nodule.

150′.7″ — LEVEL OF THE SEA.

308′.5″ — White Chalk, with beds of black Flints.

459′.0″

82′.0″ — Grey Chalk, alternating with Marl and Flints.

541′.0″

316.

987′.7″ — Grey Chalk, very compact, alternating with beds of micaceous Clay.

1528′.7″

89′.6″ — Chalk Marl.

1618′.1″

189′.8″ — Upper Greensand and Gault, composed of micaceous Clays, blue, green, and black, with fossils and pyrites.

1806′.9″ — Lower Greensand.

cipal Council; but it in no respect affects the choice of the boring machinery, which seems to have complied with all the conditions it was designed to meet. The descent of the tubes and their nature ought to have been the subject of special study by the engineers of the town, who should have known the nature of the strata to be traversed better than Kind could be supposed to do, and should have insisted upon the tubing being executed of cast or wrought iron, so as effectually to resist the passage of the water. At any rate, this precaution ought to have been taken in the portions of the well carried through the basement beds of the Paris basin, or through the lower members of the chalk and the upper greensand. It may also be observed that a remarkable change has been noticed in connection with the subterranean disturbances which have lately taken place in France. The water in this well is at these times rendered thick, cloudy, and totally unfit for human consumption. The discolouration of the water, however, is not dependent upon this cause, but is owing to the strata through which the boring passes being washed out, which is in itself a serious objection to the use of the water of this well.

The system applied by Dru is worthy of attention, not so much on account of the novelty of the invention, or of any new principle involved in it, as on account of the contrivances it contains for the application of the tool, "*à chute libre*," or the free-falling tool, to artesian wells of large diameters. It has been already explained, that under Kind's arrangements the trepan was thrown out of gear by the reaction of the water which was allowed to find its way into the column of the excavation; but that it is not always possible to command the supply of the quantity necessary for that purpose; and even when possible, the clutch Kind adopted was so shaped as to be subject to much and rapid wear. Dru, with a view to obviate both these inconveniences, made his trepan in the manner shown in Fig. 335, in which it will be seen that the tool was gradually raised until it came in contact with the fixed part of the upper machinery, when it was thrown out of gear. The bearings of the clutch were parallel to the horizontal line, and were found in practice to be more evenly worn, so that this instrument could be worked sometimes from eight days to fourteen days without intermission; whereas, on Kind's system, the trepan was frequently withdrawn after two days' or three days' service. Another great recommendation of Dru's system, if applied in cases where water is scarce, is that there is no necessity for a column of water with the trepan; but in all other essential respects the details of his machinery are the same as those employed by Kind, who must be considered to have advanced the science of well-boring by the introduction of timber-rods, the manner of balancing them, and by the use of the trepan, all of which were first applied at the artesian boring of Passy, and enabled it to be executed in a comparatively short space of time. The tools introduced by Dru and other modern well-borers are doubtlessly better fitted for the artesian borings of small diameter, and for such as are free from water from the upper strata; but the advantage ceases when these conditions are reversed.

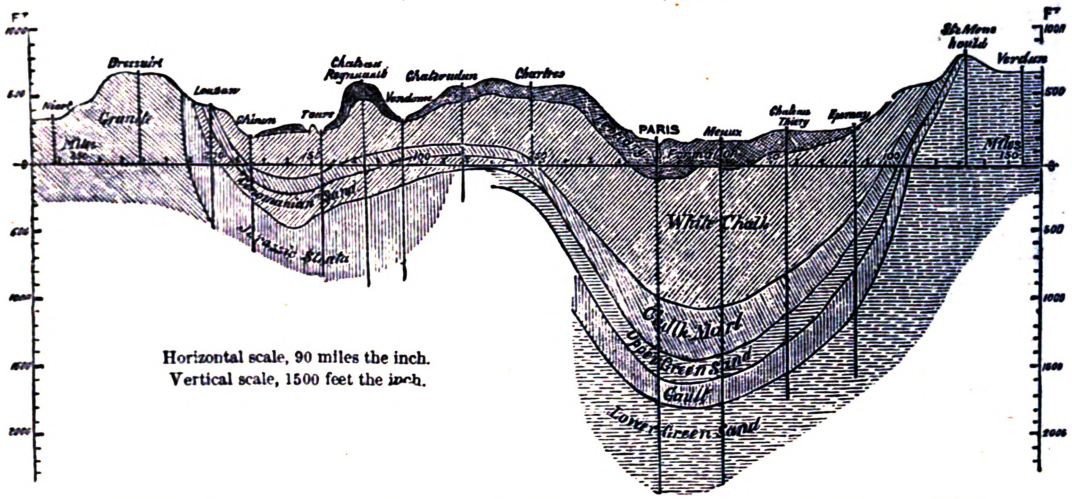
The nature and depths of the different strata bored through in sinking an artesian well at Kentish Town, London are shown in Fig. 344; Fig. 345 shows the nature and extent of the strata that were met in boring the artesian well at Passy, Paris; and Fig. 346, in a similar manner, exhibits the range and nature of the strata perforated in boring the artesian well at Grenelle, to which we have so often referred.

We take an account of some recent operations in artesian well-boring by M. Dru, of Paris, from a paper read by him at the Conservatoire des Arts et Métiers, Paris, 6th June, 1867, and published in the 'Proceedings of the Institute of Mechanical Engineers.'

The artesian wells at present sunk in the tertiary formation of the Paris basin, Fig. 347, range in size generally from about 8 in. down to 2 in. diameter, with a depth of about 230 to 350 ft.

347.

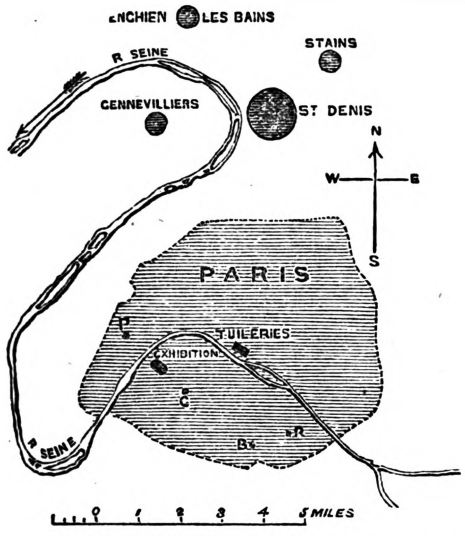
*Geological Section from Niort to Verdun, through the Paris basin.*




The bore-hole is usually lined with copper, in order to make the wells water-tight and bring the water to the surface without loss. These works often present considerable difficulties in their execution, from the frequent changes in the nature of the ground passed through, and from the impediments that are so often encountered in driving the tubes through the beds of sand and clay.

Borings of a much greater depth and larger size are now in process of execution in Paris, for the purpose of bringing to the surface a large supply of the artesian waters from the lower greensand underlying the chalk, in the secondary formation; the existence of a supply of water in that stratum has already been proved by the well sunk at Grenelle of 3¾ in. diameter, and the subsequent one of 27½ in. diameter sunk at Passy. Each of these two artesian wells required six or seven years' work for its completion; their situation in Paris is shown in the plan, Fig. 348.

348.

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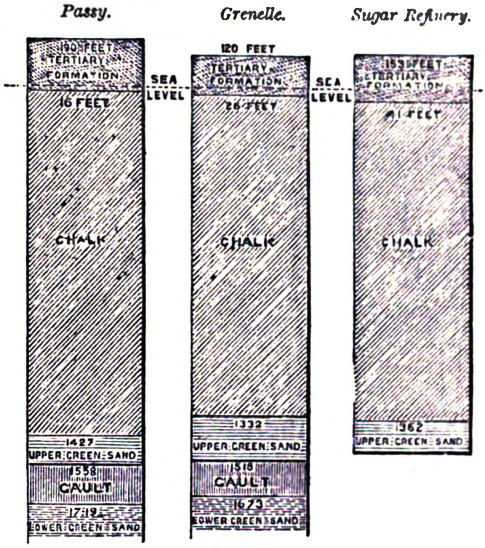



*Reference.*—P, Passy Well. G, Grenelle. B, Butte-aux-Cailles. R, Sugar Refinery.

A large artesian well was, in 1867, being constructed by Dru at Butte-aux-Cailles, Fig. 348, for the supply of the city of Paris, which is intended to be carried down through the greensand to a depth of 2600 or 2900 ft. to reach the Portland limestone. The boring in 1867 was 490 ft. deep, and its diameter 47 in.

During the previous 2½ years, M. Dru was engaged in sinking a similar well of 19 in. diameter for supplying the Sugar Refinery of M. Say, in Paris, Fig. 349; 1570 ft. deep of this well had been bored in 1867, see Fig. 349.

For the smaller wells, hand-boring tools are in use; but these are limited to borings of inconsiderable depth and small diameter. For borings of the diameter of these large wells, it is necessary to make use of special tools, worked entirely by steam-power; and in some cases of sinking mine-shafts, tools of as large a diameter as 14¾ ft. have been used. The boring is effected by a rotary motion in the case of the small diameters; but in borings of a large diameter and considerable depth, percussive action alone is employed, which is effected by raising the tool and letting it fall with successive strokes.

The apparatus employed by M. Dru in boring the large wells that have been mentioned, is shown in Figs. 350, 351. The boring-rod A is suspended from the outer end of the working beam B, which is made of timber hooped with iron, working upon a middle bearing, and is connected at the inner end to the vertical steam cylinder C, of 10 in. diameter and 39 in. stroke. The stroke of the boring-rod is reduced to 22 in., by the inner end of the beam being made longer than the outer end, serving as a partial counterbalance for the weight of the boring-rod. The steam cylinder is shown enlarged in Fig. 352, and is single-acting, being used only to lift the boring-rod at each stroke, and the rod is lowered again by releasing the steam from the top side of the piston; the stroke is limited by timber stops both below and above the end of the working beam B.

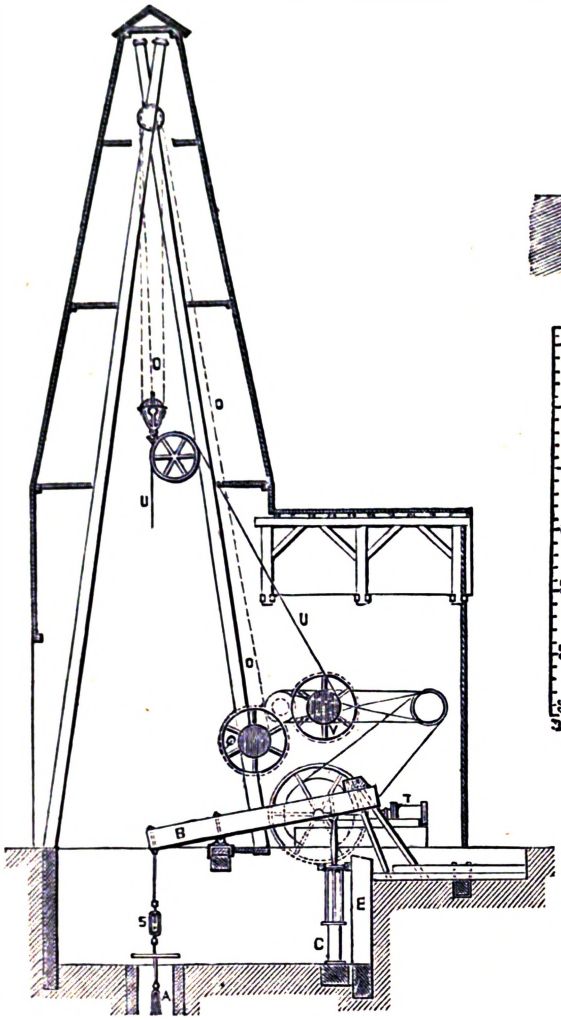
The boring-tool is the part of most importance in the apparatus, and the one that has involved most difficulty in maturing its construction. The points to be aimed at in this are,—simplicity of construction and repairs· the greatest force of blow possible for each unit of striking-surface, and freedom from liability to get turned aside and choked.

The tool used in small borings is a single chisel, as shown in Figs. 353, 354; but for the large borings it is found best to divide the tool-face into separate chisels, each of convenient size and weight for forging. All the chisels, however, are kept in a straight line, whereby the extent of striking-surface is reduced; and the tool is rendered less liable to be turned aside by meeting a hard portion of flint on a single point of the striking-edge, which would diminish the effect of the blow.

The tool is shown in Figs. 355, 356, 357, 358, 359, 360, 361; and is composed of a wrought-iron body D, connected by a screwed end, E, to the boring-rod, and carrying the chisels, F F, fixed in separate sockets and secured by nuts above; two or four chisels are used, or sometimes even a greater number, according to the size of the hole to be bored. This construction allows of any broken chisel being easily replaced; and also, by changing the breadth of the two outer chisels, the diameter of the hole bored can be regulated exactly as may be desired. When four chisels are used, the two centre ones are made a little longer than the others, as shown in Fig. 359, to form a leading hole as a guide to the boring-rod. A cross-bar G, of the same width as the tool, guides

it in the hole in the direction at right angles to the tool; and in the case of the larger and longer tools a second cross-bar is also added higher up, at right angles to the first and parallel to the striking-edge of the tool.

350.

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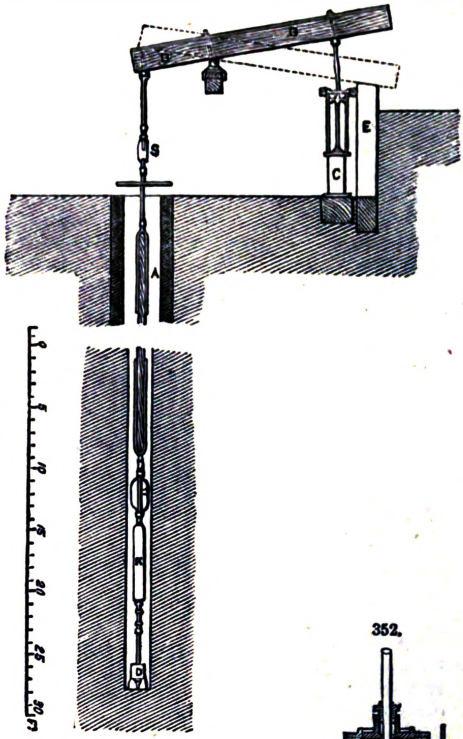


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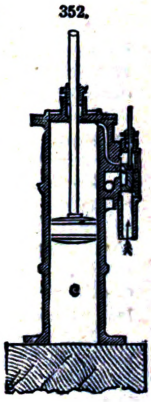

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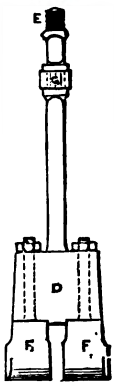
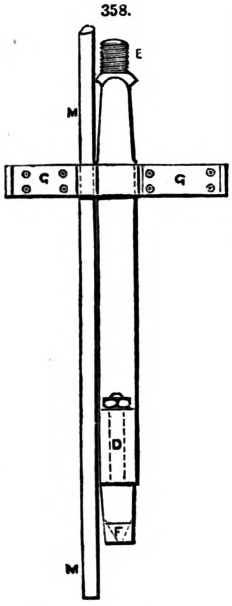
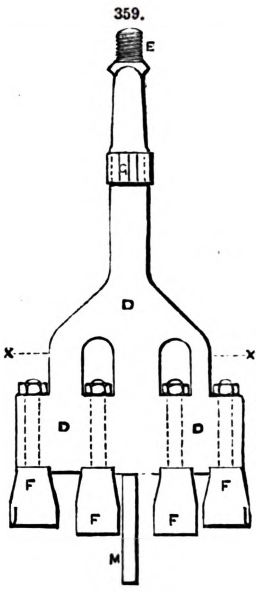



357.

If the whole length of the boring-rod were allowed to fall suddenly to the bottom of a large bore-hole at each stroke, frequent breakages would occur; it is therefore found requisite to arrange for the tool to be detached from the boring-rod at a fixed point in each stroke, and this

has led to the general adoption of *free-falling tools*. There have been several contrivances for effecting this object, and M. Dru's plan of self-acting free-falling tool liberated by reaction, is



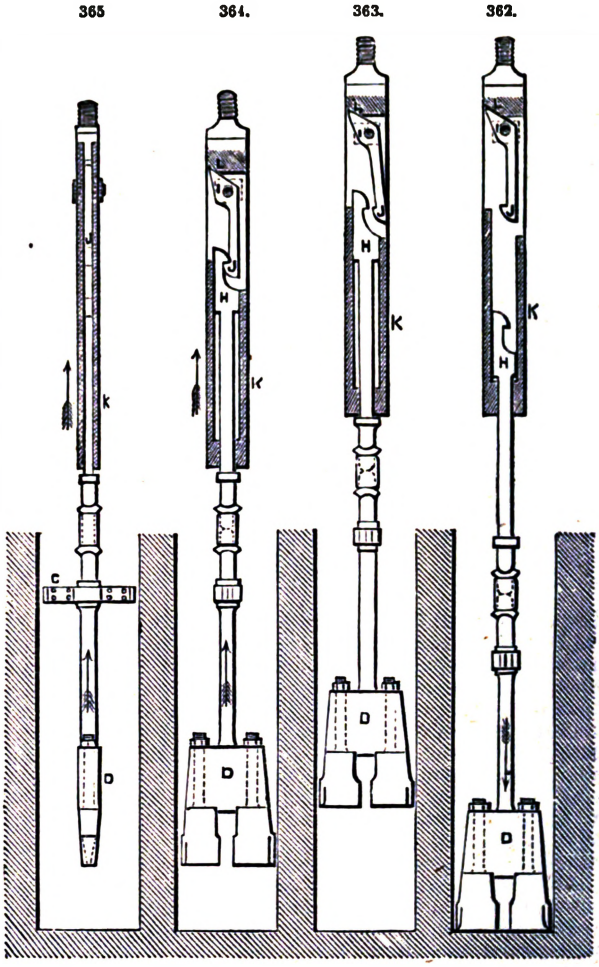
shown in side and front view in Figs. 362, 363. The hook H, attached to the head of the boring-tool D, slides vertically in the box K, which is screwed to the lower extremity of the boring-rod; and the hook engages with the catch, J, centred in the sides of the box K, whereby the tool is lifted as the boring-rod rises. The tail of the catch, J, bears against an inclined plane, L, at the top of the box K; and the two holes carrying the centre-pin, I, of the catch, are made oval in the vertical direction, so as to allow a slight vertical movement of the catch. When the boring-rod reaches the top of the stroke, it is stopped suddenly by the tail end of the beam B, Fig. 351, striking upon the wood buffer-block E; and the shock thus occasioned causes a slight jump of the catch, J, in the box K; the tail of the catch is thereby thrown outwards by the incline L, as shown in Fig. 364, liberating the hook H, and the tool then falls freely to the bottom of the bore-hole, as shown in Fig. 365. When the boring-rod descends again after the tool, the catch, J, again engages with the hook H, enabling the tool to be raised for the next blow, as in Fig. 363.

Another construction of self-acting free-falling tool, liberated by a separate disengaging-rod, is shown in side and front view in Figs. 366, 367. This tool consists of four principal pieces, the hook H, the catch J, the paul I, and the disengaging-rod M. The hook H, carrying the boring-tool D, slides between the two vertical sides of the box K, which is screwed to the bottom of the boring-rod; and the catch, J, works in the same space upon a centre-pin fixed in the box, so that the tool is carried by the rod, when hooked on the catch, as shown in Fig. 367. At the same time the paul I, at the back of the catch, J, secures it from getting unhooked from the tool; but this paul is centred in a separate sliding hoop, N, forming the top of the disengaging-rod M, which slides freely up and down within a fixed distance upon the box K; and in its lowest position the hoop, N, rests upon the upper of the two guides P P, Fig. 366, through which the disengaging-rod, M, slides outside the box K. In lowering the boring-rod, the disengaging-rod, M, reaches the bottom of the bore-hole first, as shown in Figs. 366, 367, and being then stopped it prevents the paul, I, from descending any lower; and the inclined back of the catch, J, sliding down past the paul, the latter forces the catch out of the hook H, as shown in Fig. 368, thus allowing the tool, D, to fall freely and strike its blow. The height of fall of the tool is always the same, being determined only by the length of the disengaging-rod M.

The blow having been struck, and the boring-rod continuing to be lowered to the bottom of the hole, the catch, J, falls back into its original position, and engages again with the hook H, as shown in Fig. 369, ready for lifting the tool in the next stroke. As the boring-rod rises, the tail of the catch, J, trips up the paul, I, in passing, as shown in Fig. 370, allowing the catch to pass freely; and the paul before it begins to be lifted returns to the original position, shown in Fig. 367, where it locks the catch J, and prevents any risk of its becoming unhooked either in raising or lowering the tool in the well.

The boring-tool shown in Figs. 355, 356, which is employed in boring the well of 19 in. diameter at the Sugar Refinery, weighs ¾ ton, and is liberated by reaction, by the arrangement shown in Figs. 362 to 365; and the same mode of liberation was applied in the first instance to the larger tool, shown in Figs. 358 to 361, employed in sinking the well of 47 in. diameter at Butte-aux-Cailles. The great weight of the latter tool, however, amounting to as much as 3½ tons, necessitated so violent a shock for the purpose of liberating the tool by reaction, that the boring-rods and the rest of the apparatus would have been damaged by a continuance of that mode of working; and M. Dru was therefore led to design the arrangement of disengaging-rod for releasing the tool, as shown in Figs. 366, 367. This mode of liberation is consequently the one

now in use at Butte-aux-Cailles, where it has proved completely successful in practical working. In this case the cross-guide, G, fixed upon the tool is made with an eye for the disengaging-rod, M, to work through freely, as shown in Figs. 358, 360. For borings of small diameter, however, the disengaging-rod cannot supersede the reaction system of liberation, as the latter alone is able to work in borings as small as 3¼ in. diameter; and a bore-hole no larger than this diameter has been successfully completed by M. Dru with the reaction-tool to a depth of 750 ft.




The boring-rods employed are of two kinds, wrought iron and wood. The wood rods, shown in Figs. 351, 371, are used for borings of large diameter, as they possess the advantage of having a larger section for stiffness without increasing the weight; and also when immersed in water the greater portion of their weight is floated. The wood for the rods requires to be carefully selected, and care has to be taken to choose the timber from the thick part of the tree, and not the toppings. In France, Lorraine, or Vosges, deals are preferred.

The boring-rods, whether of wood or iron, are screwed together either by solid sockets, as in Fig. 372, or with separate collars, as in Fig. 373. The separate collars are preferred for the purpose, on account of being easy to forge; and also because, as only one-half of the collar works in coupling and uncoupling the rods, while the other half is fixed, the screw-thread becomes worn only at one end, and by changing the collar, end for end, a new thread is obtained when one is worn out, the worn end being then jammed fast as the fixed end of the collar.

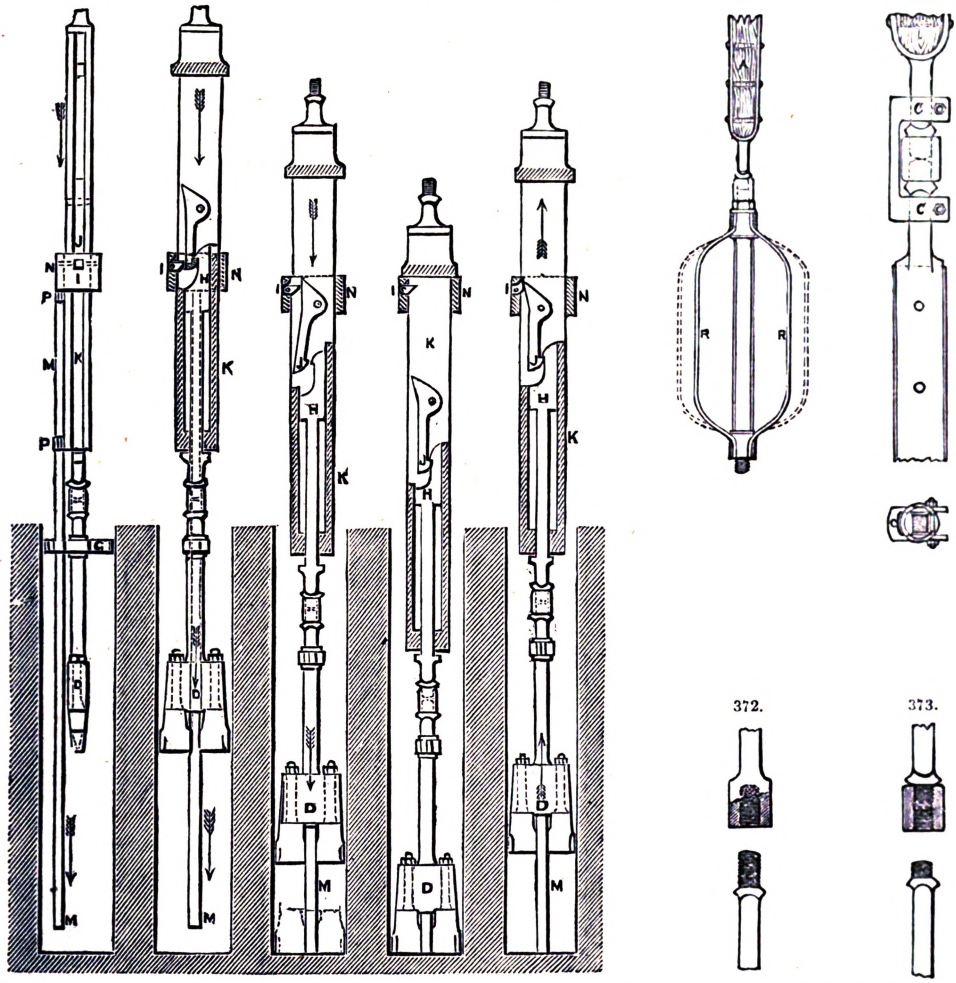
The boring-rod is guided in the lower part of the hole by a lantern R, Fig. 351, shown to a larger scale in Figs. 371, 374, which consists of four vertical iron bars curved in at both ends, where they are secured by movable sockets upon the boring-rod, and fixed by a nut at the top. By changing the bars, the size of the lantern is readily adjusted to any required diameter of bore-hole, as indicated by the dotted lines. In raising up or letting down the boring-rod, two lengths of about 30 ft. each are detached or added at once, and a few shorter rods of different lengths are used to make up the exact length required. The coupling-screw S, Fig. 351, by which the boring-rod is connected to the working-beam B, serves to complete the adjustment of length; this is turned by a cross-bar, and then secured by a cross-pin through the screw.

In ordinary work, breakages of the boring-rod generally take place in the iron, and more particularly at the part screwed, as that is the weakest part. In the case of breakages, the tools usually employed for picking up the broken ends are a conical screwed socket, shown in Fig. 375, and a claw, shown in Fig. 376; the socket being made with an ordinary V-thread for cases where the breakage occurs in the iron; but having a sharper thread, like a wood screw, when used where the breakage is in one of the wood rods. In order to ascertain the shape of the fractured end left in the bore-hole, and its position relatively to the centre line of the hole, a similar conical socket is first lowered, having its under-surface filled up level with wax, so as to take an impression of the broken end, and show what size of screwed socket should be employed for getting it up. Tools with nippers are sometimes used in large borings, as it is not advisable to subject the rods to a twist.

When the boring-tool has detached a sufficient quantity of material, the boring rod and tool are drawn up by means of the rope O, Fig. 350, winding upon the drum Q, which is driven by straps and gearing upon the steam-engine T. A scoop is then lowered into the bore-hole by the wire-rope U, from the other drum V, and is afterwards drawn up again from the excavated material. A friction-break is applied to the drum Q, for regulating the rate of lowering the boring-rod down the well. The scoop, shown in Figs. 377, 378, consists of a riveted iron cylinder, with a handle at the top, which can either be screwed to the boring-rod or attached to the wire-rope; and the bottom is closed by a large valve, opening inwards. Two different forms of valve are used, either

a pair of flap-valves, as shown in Fig. 378, or a single-cone valve, Fig. 379; and the bottom ring of the cylinder, forming the seating of the valve, is forged solid, and steeled on the lower edge.

366. 367 368. 369. 370. 371. 373.

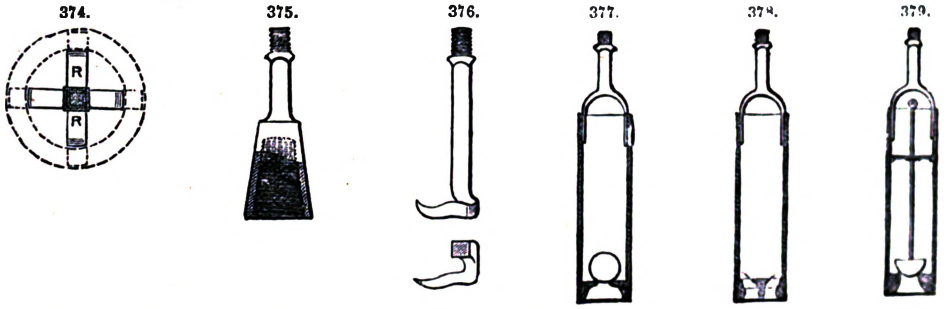



372. 373.



On lowering this cylinder to the bottom of the bore-hole, the valve opens, and the loose material enters the cylinder, where it is retained by the closing of the valve, whilst the scoop is drawn up again to the surface. In boring through chalk, as in the case of the deep wells in the Paris basin, Fig. 347, the hole is first made of about half the final diameter for 60 to 90 ft. depth, and it is then enlarged to the full diameter by using a larger tool. This is done for convenience of working; for if the whole area were acted upon at once, it would involve crushing all the flints in the chalk; but, by putting a scoop in the advanced hole, the flints that are detached during the working of the second larger tool are received in the scoop and removed by it, without getting broken by the tool.

374. 375. 376. 377. 378. 379.




The resistance experienced in boring through different strata is various; and some rocks passed through are so hard, that with 12,000 blows a-day of a boring-tool weighing nearly 10 cwt., with 19 in.

height of fall, the bore-hole was advanced only 3 to 4 in. a-day. As the opposite case, strata of running sand have been met with so wet, that a slight movement of the rod at the bottom of the hole was sufficient to make the sand rise 30 to 40 ft. in the bore-hole. In these cases M. Dru has adopted the Chinese method of effecting a speedy clearance, by means of a scoop closed by a large ball-clack at the bottom, as shown in Fig. 377, and suspended by a rope, to which a vertical movement is given; each time the scoop falls upon the sand a portion of this is forced up into the scoop, and retained there by the ball-valve.

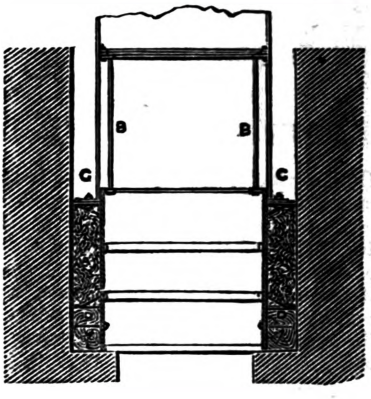
An artesian well is always some time in settling down to its permanent working state, generally one or two months; and when the water first reaches the surface it undergoes considerable fluctuations, being charged from time to time with the substances at the bottom of the bore-hole. In the Grenelle well there were fluctuations at starting of 300 ft. in the height of the water. The velocity of the flow of water from the artesian wells varies considerably, and the following are some examples of the delivery at the surface by those already completed in the Paris basin:—

| | Depth of Bore-hole. | Diameter of Bore-hole. | Gallons delivered per minute. | Velocity of discharge. Feet per second. |
|---|---|---|---|---|
| | feet. | inches. | | |
| St. Denis, Hôtel Dieu .. | 262 | 2·28 | 28 | 2·68 |
| Gennevilliers .. .. .. | 312 | 2·28 | 31 | 2·89 |
| Stains .. .. .. .. | 266 | 2·95 | 176 | 9·87 |
| Elbeuf .. .. .. .. | 492 | 2·95 | 66 | 3·71 |
| Paris, Grenelle .. .. | 1795 | 3·74 | 484 | 16·63 |
| „ Passy .. .. .. | 1923 | 27·56 | 1980 | 1·64 |

The localities of these wells are shown in the plan, Fig. 348; and Fig. 347 is a geological section passing through the Paris basin. Sections of the strata bored through in the wells at Passy and Grenelle are shown in Fig. 349; and a section in the boring now in progress at the Sugar Refinery is shown in the same Figure. In the case of the artesian well at Grenelle, the water is carried up to a height of 128 ft. above the ground by a stand-pipe of 3·74 in. bore, from the top of which the water overflows at the rate of 100 gallons a-minute, with a velocity of 3·94 ft. a-second.

Borings of large diameter, for mines or other shafts, are also sunk by means of the same description of boring-tools, only considerably increased in size, extending up to as much as 14 ft. diameter. The well is then lined with cast-iron or wrought-iron tubing, for the purpose of making it water-tight; and a special contrivance, invented by Kind, has been adopted for making a water-tight joint between the tubing and the bottom of the well, or with another portion of tubing previously lowered down. This is done by a stuffing-box, shown in Fig. 380, which contains a packing of moss at A A. The upper portion of the tubing is drawn down to the lower portion by the tightening-screws B B, so as to compress the moss-packing when the weight is not sufficient for the purpose. A space, C, is left between the tubing and the side of the well, to admit of the passage of the stuffing-box flange, and also for running in concrete for the completion of the operation. The moss-packing rests upon the bottom flange D; but this flange is sometimes omitted. The joint is thus simply made by pressing out the moss-packing against the sides of the well; and this material, being easily compressible and not liable to decay under water, is found to make a very satisfactory and durable joint.

380.




M. Dru states that the reaction-tool has been successfully employed for borings up to as large as about 4 ft. diameter, as in the case of the well at Butte-aux-Cailles of 47 in. diameter; but beyond that size he considers the shock requisite to liberate the larger and heavier tool would probably be so excessive, as to be injurious to the boring-rods and the rest of the attachments; and he therefore designed the arrangement of the disengaging-rod for liberating the tool in borings of large diameter, whereby all shock upon the boring-rods was avoided and the tool was liberated with complete certainty.

In practice it is necessary to turn the boring-tool partly round between each stroke, so as to prevent it from falling every time in the same position at the bottom of the well; and this was effected in the well at Butte-aux-Cailles by manual-power at the top of the well, by means of a long hand-lever fixed to the boring-rod by a clip bolted on, which was turned round by a couple of men through part of a revolution during the time that the tool was being lifted. The turning was ordinarily done in the right-hand direction only, so as to avoid the risk of unscrewing any of the screwed couplings of the boring-rods; and care was taken to give the boring-rod half a turn when the tool was at the bottom, so as to tighten the screw-couplings, which otherwise might shake loose. In the event of a fracture, however, leaving a considerable length of boring-rod in the hole, it was sometimes necessary to have the means of unscrewing the couplings of the portion left in the hole, so as to raise it in parts, instead of all at once. In that case a locking-clip was added at each screwed joint above, and secured by bolts, as shown at C in Fig. 373, at the time of

putting the rods together for lowering them down the well to recover the broken portion; and by this means the ends of the rods were prevented from becoming unscrewed in the coupling-sockets, when the rods were turned round backwards for unscrewing the joints in the broken length at the bottom of the bore-hole.

M. Dru states that in his own experience, owing to the difficulties attending the operation, the occurrence of delays from accidents was the rule, while the regular working of the machinery was the exception. He also states that, although the chisel-shaped tools previously described were the form principally employed, he considers it would be a mistake to attempt to use any one form of tool exclusively for all descriptions of ground. For passing through granite, or any other primary rock, a percussive action is indispensable, and the force of the blow is required to be concentrated upon a small extent of cutting-edge, in order to produce any effect by the blow; but in softer ground a greater number of cutting-chisels are used in the falling-tool.

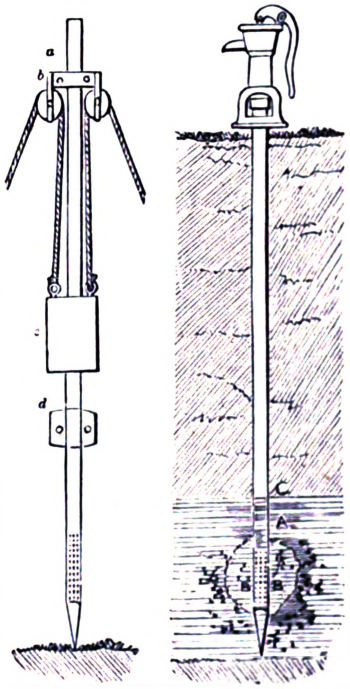
As long ago as 1842 ropes have been used in France for boring purposes, but they have not been found to answer in boring through clay, because the tool becomes choked and sticks fast, and the rope breaks, leaving the tool imbedded at the bottom of the bore-hole: it is then necessary to have recourse to rods for raising the boring-tool, and M. Dru therefore preferred to use rods in the first instance. In boring through sand, however, ropes have been successfully employed, and by this means borings have been carried down with great rapidity, as much as 60 ft. depth having been accomplished in a fortnight through a bed of sand in boring a well in the upper stratum of the Paris basin. The section of the Paris basin shows that, owing to the variable strata to be passed through, no one form of boring-tool, such as has been referred to, could be used for all parts of the bore-hole, but different tools were required, according to the particular stratification at the bottom of the hole.

When running sands are met with, the plan adopted is to use the Chinese ball-scoop, Fig. 377, described for clearing the bottom of the bore-hole; and where there is too much sand for it to be got rid of in this way, a tube has to be sent down from the surface to shut off the sand. This, of course, necessitates diminishing the diameter of the hole in passing through the sand; but on reaching the solid rock below the running sand, an expanding tool is used for continuing the bore-hole below the tubing with the same diameter as above it, so as to allow the tubing to go down with the hole.

In the case of meeting with a surface of very hard rock at a considerable inclination to the bore-hole, M. Dru employs a tool, the cutters of which are fixed in a circle all round the edge of the tool, instead of in a single diameter line; the length of the tool is also considerably increased in such cases, as compared with the tools used for ordinary work, so that it is guided for a length of as much as 20 ft. He uses this tool in all cases where from any cause the hole is found to be going crooked, and has even succeeded by this means in straightening a hole that had previously been bored crooked.

The cutting action of this tool is all round its edge; and therefore in meeting with an inclined hard surface, as there is nothing to cut on the lower side, the force of the blow is brought to bear on the upper side alone, until an entrance is effected into the hard rock in a true straight line with the upper part of the hole.

381. 382.




*Norton's patent Tube Well.*—This well consists of a hollow wrought-iron tube about $1\frac{3}{4}$ in. diameter, composed of any number of lengths from 3 to 11 ft., according to the depth required. The water is admitted into the tube through a series of holes, which extend up the lowest length to a height of $2\frac{1}{2}$ ft. from the bottom.

The position for a well having been selected, a vertical hole is made in the ground with a crow-bar to a convenient depth; the well-tube *a*, having the clamp *d*, monkey *c*, and pulleys *b*, Fig. 381, previously fixed on it, is inserted into this hole.

The clamp is then screwed firmly on to the tube from 18 in. to 2 ft. from the ground, as the soil is either difficult or easy; each bolt being tightened equally, so as not to indent the tube.

The pulleys are next clamped on to the tube at a height of about 6 or 7 ft. from the ground, the ropes from the monkey having been previously rove through them.

The monkey is raised by two men pulling the ropes at the same angle. They should stand exactly opposite each other, and work together steadily, so as to keep the tube perfectly vertical, and prevent it from swaying about while being driven. If the tube shows an inclination to slope towards one side, a rope should be fastened to its top and kept taut on the opposite side, so as gradually to bring the tube back to the vertical. When the men have raised the monkey to within a few inches of the pulleys, they lift their hands suddenly, thus slackening the ropes and allowing the monkey to descend with its full weight on to the clamp. The monkey is steadied by a third man, who also assists to force it down at each descent. This man, likewise, from time to time, with a pair of gas-tongs, turns the tube round in the ground, which assists the process of driving, particularly when the point comes in contact with stones.

Particular attention must be paid to the clamp, to see that it does not move on the tube; the bolts must be tightened up at the first appearance of any slipping.

When the clamp has been driven down to the ground, the monkey is raised off it, the screws of the clamp are slackened, and the clamp is again screwed to the tube, about 18 in. or 2 ft. from the ground. After this, the monkey is lowered on to it, and the pulleys are then raised until they are again 6 or 7 ft. from the ground.

The driving is continued until but 5 or 6 in. of the well-tube remain above the ground, when the clamp, monkey, and pulleys are removed, and an additional length of tube screwed on to that in the ground. This is done by first screwing a collar on to the tube in the ground, and then screwing the next length of tube into the collar, till it buts against the lower tube; a little white-lead must be placed on the threads of the collar before the ends of the tubes are screwed into it.

The driving can thus be continued until the well has obtained the desired depth. Soon after another length has been added, the upper length should be turned round a little with the gas-tongs, to tighten the joints, which have a tendency to become loose from the jarring of the monkey. Care must be taken, after getting into a water-bearing stratum, not to drive through it, owing to anxiety to get a large supply. From time to time, and always before screwing on an additional length of tube, the well should be sounded, by means of a small lead attached to a line, to ascertain the depth of water, if any, and character of the earth which has penetrated through the holes perforated in the lower part of the well-tube. As soon as it appears that the well has been driven deep enough, the pump is screwed on to the top and the water drawn up. It usually happens that the water is at first thick, and comes in but small quantities; but after pumping for some little time, as the chamber round the bottom of the well becomes enlarged, the quantity increases and the water becomes clearer.

When sinking in gravel or clay, the bottom of the well-tube is liable to become filled up by the material penetrating through the holes; and before a supply of water can be obtained, this accumulation must be removed by means of the cleaning-pipes.

The cleaning-pipes are of small diameter, ¼-in. externally, and the several lengths are connected together in the same way as the well-tubes, by collars screwing on over the adjoining end of two pipes.

To clear the well, one cleaning-pipe after another is lowered into the well, until the lower end touches the accumulation; the pipes must be held carefully, for if one were to drop into the well it would be impossible to get it out without drawing the well. A pump is then attached to the upper cleaning-pipe by means of a reducing-socket; the lower end of the cleaning-pipe is then raised and held about an inch above the accumulation by means of the gas-tongs: water is next poured down the well outside the cleaning-pipe, and, being pumped up through the cleaning-pipe, brings up with it the upper portion of the accumulation; the cleaning-pipe is gradually lowered, and the pumping continued until the whole of the stuff inside the well-tube is removed. The pump is then removed from the cleaning-pipe, and the cleaning-pipes are withdrawn piece by piece; and finally the pump is screwed on to the upper end of the tube-well, Fig. 382, which is then in working order.

The tube being very small, is in itself capable of containing only a very small supply of water, which would be exhausted by a few strokes of the pump, the condition, therefore, upon which alone these tube-wells can be effective, is that there shall be a free flow of water from the outside through the apertures into the lower end of the tube. When the stratum in which the water is found is very porous, as in the case of gravel and some sorts of chalk, the water flows freely; and a yield has been obtained in such situations as great and rapid as the pump has been able to lift, that is 600 gallons an hour. In some other soils, such as sandy loam, the yield in itself may not be sufficiently rapid to supply the pump; in such cases, the effect of constant pumping is to draw up with the water from the bottom a good deal of clay and sand, and so gradually to form a reservoir, as it were, around the foot of the tube, in which water accumulates when the pump is not in action, as is the case in a common well. In dense clays, however, of a close and very tenacious character, the American tube-well is not applicable, as the small perforations become sealed, and water will not enter the tube. When the stratum reached by driving is a quicksand, the quantity of sand drawn up from the water will be so great, that a considerable amount will have to be pumped before the water will come up clear; and even in some positions, when the quicksand is of great extent, the effect of the pumping may be to injure the foundations of adjoining buildings on the surface of the ground.

The tube-well cannot itself be driven through rock, although it might be used for drawing water from a subjacent stratum through a hole bored in the rock to receive it.

Subject to these conditions, these tube-wells afford a ready and economical means for drawing water to the surface from a depth not exceeding 27 or 28 ft.

*Works and Papers on Artesian Wells*:—Garnier, F., 'Traite sur les Puits Artésiens,' 4to, Paris, 1826. Héricourt de Thury, 'Considérations Geologiques et Physiques sur la cause du Jaillissement des Eaux des Puits Fores, 8vo, Paris, 1829. Degoussee et Saurent, 'Guide du Sondeur,' 3 vols., Paris, 1861. G. R. Burnell, 'On Artesian Wells,' Transactions Inst. C. E., 8vo, 1864. B. Latham, 'Papers on Water Supply,' Part I., 8vo, 1865. Van Ertborn, 'Mémoire sur les Puits Artésiens,' 8vo, Anvers, 1866. Dru, 'On the Machinery for Boring Artesian Wells,' Proceedings Inst M. E., 1867.

ARTIFICIAL STONE. Fr., *Pierre artificielle*; Ger., *Künstlicher Stein*; Ital., *Pietra artifiziale*; Span., *Piedra artificial*.

See Stone.

ARTILLERY. Fr., *Artillerie*; Ger., *Artillerie*; Ital., *Artiglieria*; Span., *Artilleria*.

The term artillery is applied to all descriptions of ordnance, whether light or heavy, and everything required for their service.

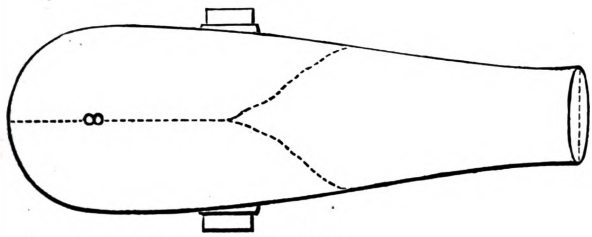
A chief point in the science of gunnery, and one which limits its future, is the construction of

guns of sufficient strength to curb and govern the utmost force of any explosive compound which may be used in them.

No modern theory of constructing guns can be called new, since guns are in existence that have been either recovered from wrecks, or preserved in other ways, showing every variety of coils, hoops, casting, wire-binding, and so on, as far as the appliances then in use could furnish the quondam inventors with means of carrying their inventions into effect. That in which novelty has been attained, is the improvement of processes by which large castings or forgings, accurate turning and boring, can be secured, or by which chemical knowledge can be brought to bear on the manipulation of metals; but no such progress can make a built-up gun, or machine of any sort, stronger than a perfectly homogeneous one, in which the varying strains are closely calculated, and properly met by the scientific disposition of the necessary strength. Thus, while we admire the ingenuity of the methods by which guns have been built up, we cannot think that such processes will now, more than in former times, continue to be preferred to well cast guns of good material.

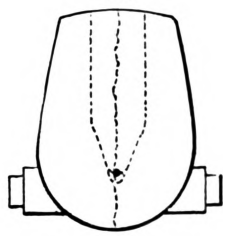
Guns are burst by two forces—the rending action of the powder gas, and the unequal heating of a nearly homogeneous metal; but it is not, as supposed by some authors, by interior cracks caused by contraction, since metals do not contract but expand by heat; and guns are often burst without such rapidity of firing as would induce sufficient heat to be felt on the outside, scarcely even on the inside of the gun. If cracks on the interior, and all observers are agreed on this point, are the first indications of the bursting of a gun—if this be accompanied by a sensible dilatation of the bore, it is clear that, as the outside of the gun has not increased, though the inside has cracked, some of the metal has been compressed into a smaller space than it previously occupied, and this compression being greatest on the inside, as shown by the greater width of crack, ought to be resisted by a metal at that point harder, that is, having greater strength to resist impact, than at any other portion of the gun. In cannon cast solid in sand and afterwards bored out, the reverse is the case. Increased thickness of metal, as trunnions or other projections, will determine in many cases the line of fracture. A muzzle swell is beneficial, as tending to prevent vibration, which is begun at the point where the projectile leaves the gun, and the true concussive explosion takes place. The cascable, also, is not arbitrary, nor alone necessary for supporting a breeching; but, like the trunnions, reinforces the gun, though, unlike them, it does so

383.

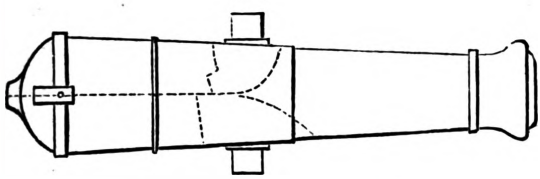


American Gun.

384.



385.



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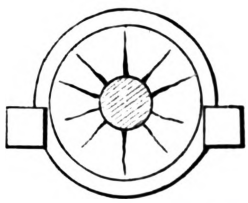
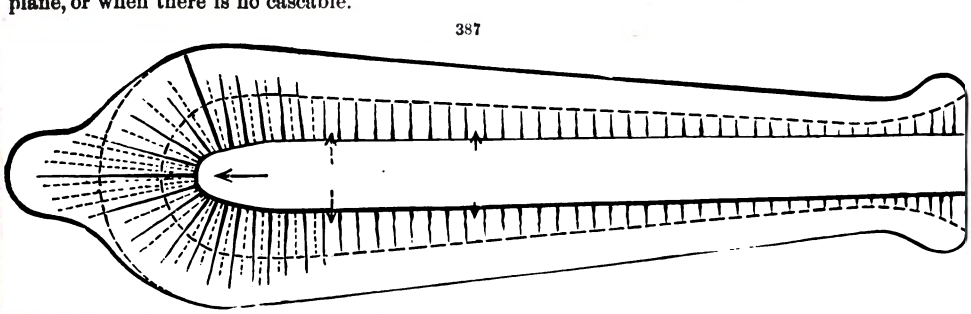


usefully, in consequence of being in the prolongation of the axis of the piece. We give two practical illustrations of the bursting of guns, Figs. 383, 385; and one of that of mortars, Fig. 384.

Fig. 386 shows the comparative intensity of strains in a gun when the trunnions are under the plane, or when there is no cascable.

387



Now let us examine the parts in which the lines of least resistance are to be found. In the gun, a radial strain, Fig. 387, is exerted on all parts of the bore equally, except to the rear, where

it is no longer radial but direct; no longer resisted by wedges, as hereafter shown, but by a cylinder of iron which terminates in the cascable. At the trunnions, too, which are not often placed in modern guns in the horizontal plane of the axis, but below it, there will be another line of least resistance where the trunnions are not, the necessary consequence of a line of greatest resistance where they are.

Still more is this seen in the mortar, Fig. 384, which has an enormously greater lateral resistance at the trunnions than at the muzzle. This would feel the want of a cascable also, were it not that the powder-chamber is conical, and smaller than the bore; but as it is, it splits open as if wedges had been driven into the muzzle—the guns as if wedges had been driven into the breech.

J. A. Longridge, in a paper "On the Construction of Artillery," read before the Institution of Civil Engineers, came to the conclusion that the required object could be attained by constructing a gun in such an initial state of equilibrium, that when the varying strain, caused by internal pressure, should come upon it, the initial strain should be equivalent to the induced strain, and the sum of the two strains constant throughout. With the view of proving the truth of these conclusions, J. A. Longridge caused a series of experiments to be made, the first of which was to ascertain the ultimate force of gunpowder. A number of cast-iron cylinders 1 in. diameter and 0·1 in. thick were prepared. They were bored and turned accurately, and purposely made of very hard, brittle iron, so as of themselves to give the minimum of strength. These cylinders were then wrapped round with iron wire, the tensile strength of which had been previously ascertained. The number of coils varied with the degree of strength required, and each coil was laid on with the initial strain, which the experimenter's calculations led him to believe would, at the moment of bursting, cause all the coils to give way together. The cylinders were filled with Government cannon-powder, and the ends secured, leaving no vent but a touch-hole the size of a small pin, through which the powder was exploded. Several of these burst; but it was found that a cylinder with ten coils of wire upon it could not be burst. The diametral section of the cast iron was 0·2 in.; and taking its strength at 8 tons the square inch, the result is

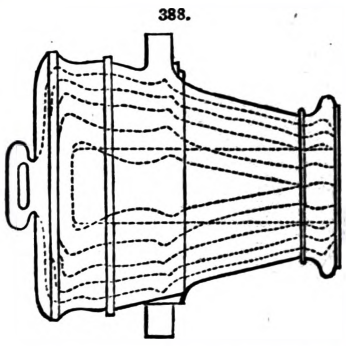
| | Tons. |
|---|---|
| $\frac{2}{10}$ths of an inch × 8 tons per square inch .. .. = | 1·6 |
| There were ten coils of wire, each wire by experiment broke with 60 lbs., and was $\frac{1}{25}$th inch in diameter; therefore the tensile strength of the two sides = 2 × 28 × 60 × 10 ÷ 2240 .. .. = | 15·0 |
| Total strength .. .. .. | 16 6 |

The internal diameter of the cylinder was 1 inch, consequently the ultimate strength of the powder did not exceed 17 tons a square inch. This must not, however, be held as the maximum effect that may be produced. The explosion of powder is more of an impact than a pressure; and although, strictly speaking, impact is only a pressure of short duration, the length of this duration is generally admitted to have great influence upon the effect produced. It has been stated that a bar to resist, with safety, the sudden application of a given pull, requires to have twice the strength that is necessary to resist the gradual application and steady action of the same pull. From this follows that, the more rapid the explosion, the greater the strain upon the gun. Not that the ultimate pressure is greater; but that, being produced in less time, its effect is greater.

The cause of weakness in a cast-iron gun is, in the first place, that the actual strength of the interior of a large gun, or mortar, is far below that of the average of ordinary castings, and always must be so whilst guns are cast solid. So long as this is the case, the outside must cool and solidify first; whilst the interior, cooling more slowly, must be drawn and rendered less dense, and consequently less resisting. This cannot be obviated by any care in selecting material.

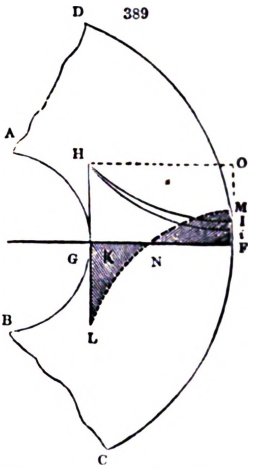
The worst part of this iron, in the chase of the gun, is afterwards bored out; but still the metal around the internal circumference is weakened below the average; and at the bottom of the powder-chamber it is in the worst possible condition. This is fully accounted for by the law of cooling. Whenever a variation in thickness occurs, a difference in the rate of cooling must also take place; this alone gives rise to a state of varied stress amongst the particles of the metal, diminishing the effect of the metal as a resisting substance. In ordinary castings this is well understood; but the same law operates in guns, though in a smaller degree; take, for instance, the accompanying sketch of a gun, Fig. 388, distorted in its proportions, for the sake of illustration, and suppose it to have cooled down after casting. Although, in the present state of our knowledge of the subject, it would be impossible to determine the absolute position of the isothermal lines at any period of cooling, yet it is certain they must approximate to the dotted lines shown in Fig. 388; and following these lines according to some definite law, would be the lines of equal stress of the particles of the gun, when cold. When, therefore, the gun is bored out, it is evident that the inner circumference of the bore must be in a state of varying strain, and that strain is one of tension. Consequently, the internal part of the gun is, throughout, in an initial state of more or less tension, and, as regards its power to resist a tensile strain, it is inferior to the normal, or average strength of the material. But beyond this, whenever a change of dimensions occurs, the cooling will give rise to varying strains, which may account for fracture taking place at those particular parts. To obviate this, wrought iron and steel have been tried, and in point of workmanship great results have been arrived at; but the same objections apply as to guns of cast iron; the inner part of the gun must be in a state of initial tension. The expense

388.



and difficulty of manufacture are also very great. As a specimen of steel manufacture, the gun forged by Krüpp, and afterwards bored and mounted in a cast-iron jacket at Woolwich, may be instanced. It was bored out to 8 in., and was from 4 to 4·5 in. thick. Taking the tensile force of hammered cast steel at 40 tons to the square inch, the resistance would be from 320 to 360 tons, which, if the strain had been uniform throughout, would have been equal to between 40 and 45 tons to the square inch on the diameter; yet the gun burst at the first discharge, with 25 lbs. of powder and a 260-lb. shot. Mallet mentions a wrought-iron 8-in. gun, forged at the Gospel Oak Iron-works, and proved at Woolwich in 1855, which burst into several pieces at the first discharge. The thickness at the breech end of this gun, which was stated to be of nearly the same dimensions as the established cast-iron guns of the same calibre, was about 9 in.; and, taking the tensile force at 20 tons to the square inch, the material, provided it had been uniformly strained, ought to have resisted a diametral strain of 360 tons, or about 45 tons to the square inch. This gun, which appeared in every respect sound to the eye and of perfect material, burst with a proof-charge of 28 lbs. of powder and two spherical 8-in. shot. The conclusion has been arrived at, that the manufacture of large forged wrought-iron guns is an operation of great difficulty, expense, and uncertainty; and however the difficulty and expense may be decreased, the uncertainty must still remain; at the best, it is but substituting for cast iron a material of higher tensile strength; the radical defect of a homogeneous mass still remaining, namely, the unequal distribution of the strain from the inner to the outer circumference. The same remarks apply with still greater force to guns of hammered cast steel, of large dimensions. The principle, which appears to be the basis of a sound and reliable construction, is that of manufacturing the gun of successive layers, laid on with an original increasing strain, from the centre to the circumference.

There is an objection to the use of hoops, from the want of continuity. The special requirement is, that each layer of the gun shall be in a definite initial state of tension or compression previous to explosion.




If, in Fig. 389, A B C D represents a portion of a section of an 8-in. gun, of which A G B is the inner and D F C the outer circumference, the state of tension of any particle between G and F may be denoted by ordinates drawn at the points in question, those above G F representing tension, and those below, compression. If, now, the gun is of any homogeneous material, such as cast iron, the state of tension at the time of explosion, and when the gun is about to burst, will be denoted by a curve H I, or H *i*. Then, supposing the tensile force of the material to be 12 tons to the square inch, and the thickness of the gun 6·5 in., when the strain at G is G H, or 12 tons, at F it is F I = 3 tons, or F *i* = 1·75 ton, according as the one or the other formula is adopted. The areas of these curves give, of course, the total strengths of the gun at the bursting point, and are found to be 36·72 tons and 30·871 tons respectively, instead of 78 tons, which it would have been if uniformly strained at 12 tons to the square inch. Now the object sought to be attained in the method of construction under consideration is, that each particle, such as K, shall, when explosion takes place, be equally strained with G. In order that this may be so, the initial state of the tension must be such as represented by the curve L N M, those between G and N being in compression, while those particles between N and M are in tension.

If, now, it is attempted to accomplish this by means of hoops, it will be found impossible, inasmuch as each hoop is a homogeneous cylinder, and follows the same law throughout its thickness, as is represented by the curve H I. Figs. 390, 391, and 392, represent the successive states of stress of rings, put on so as that when explosion takes place they shall be all equally strained at their inner circumferences. Fig. 390 shows two rings; Fig. 391 shows three rings; Fig. 392 shows four rings. The numbers denote the strains in tons per square inch. From this it will be seen that when the four rings are put on, instead of the curve L N M of Fig. 389, there are a series of abrupt changes, the two inner rings being in compression, and the two outer in tension. When the explosion takes place, the state of maximum strain is represented by Fig. 393.

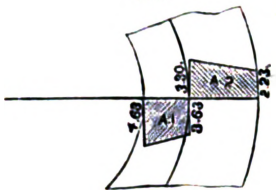
The area between the dotted and full lines shows the work done by the explosion, and, taking the total thickness of the gun, it amounts to 10·1 tons to the inch of thickness; whereas, had the construction been of very thin rings or of small wire, it would have been represented by the area between the dotted line L N M O H, Fig. 389, and would have been = 12 tons to the inch of thickness, showing a superiority of about 20 per cent. in favour of the wire over the hoops. This is upon the supposition that the workmanship of the hoops is perfect, which is not the case in practice. To afford some idea of the accuracy required, the radii of the several rings, shown in Fig. 393, are given in the following Table:—

| No. of Ring. | Inner Radius. | Outer Radius. | Thickness. | Difference. |
|---|---|---|---|---|
| 1 | 4·0000 | 5·3222 | 1·3222 | $R_1 - \rho_2 = \cdot0031$ |
| 2 | 5·3191 | 7·2928 | 1·9737 | $R_2 - \rho_3 = \cdot0035$ |
| 3 | 7·2893 | 9·4633 | 2·1740 | $R_3 - \rho_4 = \cdot0035$ |
| 4 | 9·4598 | 11·8247 | 2·3649 | |

Thus it appears, that in order to give the requisite amount of initial stress, the external radius of the first ring must be $\frac{31}{10000}$ of an inch, or about $\frac{1}{300}$ of an inch larger than the internal radius

of the second; the external radii of the second and third $\frac{35}{10000}$ of an inch greater than the internal radii of the rings next to them. Therefore, whilst the whole effect depends upon so small a quantity as about $\frac{1}{350}$ of an inch, it is evident that a very small error in workmanship will materially affect the result, and tend to deviations from the proper initial strains.

390.

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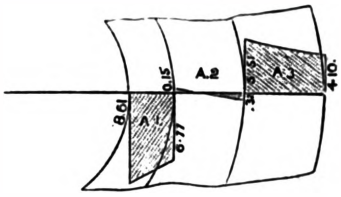
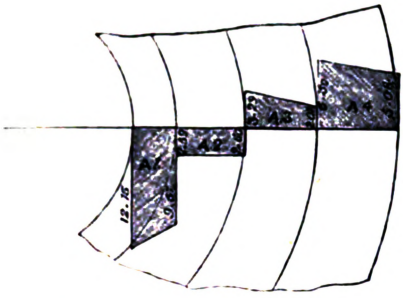



392.

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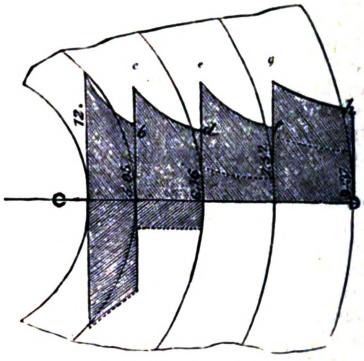
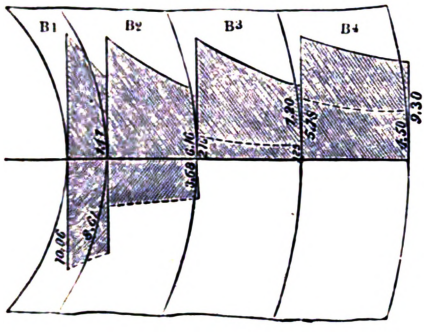


Fig 394 represents the states of stress of the rings before explosion and at the instant of maximum strain, when the rings are accurately put on.

Fig. 395 represents the states of stress of the same gun when the outer ring has been made $\frac{1}{100}$ of an inch too small.

394.

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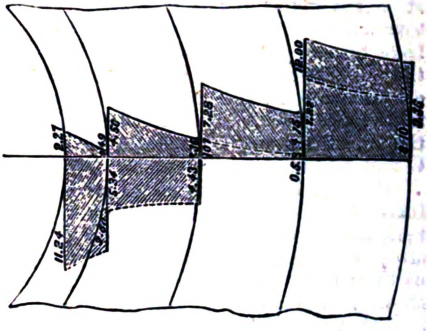
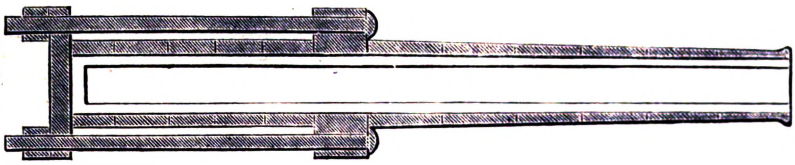


The result is, that before explosion the maximum compression of the inner ring is increased from 10·086 tons to 11·244 tons, and the maximum tension of the outer ring from 5·778 tons to 7·823 tons to the square inch; whilst at the time of maximum strain during explosion the tension of the same ring is only 2·268 tons, although the outer ring is strained to 12 tons, its assumed ultimate strength. The absolute strength of the gun is thus reduced from an average of 10·5 tons to 6 tons per inch thickness, or about 40 per cent., by an error of only $\frac{1}{100}$ of an inch in a ring about 17 inches in diameter. Rings, therefore, present practical difficulties which are entirely avoided by the use of wire, as it may be coiled on with the exact strain indicated by theory. The method adopted by J. A. Longridge was to coil a quantity of wire on a drum, fixed with its axis parallel to that of a lathe on which the gun was placed. On the axis of this drum there was another drum, to which was applied a break, similar in principle to Prony's dynamometric break, so adjusted as to give the exact tension required for each successive coil of the wire. The whole apparatus was extremely simple, and the wire laid on with great regularity. It is evident the apparatus might be so arranged that the process would proceed with the same ease and regularity as winding a thread on to a bobbin, and at the same time with the greatest accuracy as regards the initial tension. No such facility attends the use of hoops. They must be accurately bored; and after each layer is put on, the gun must be placed in the lathe, and the hoops turned on the outside. Great accuracy is indispensable; and not only is the amount of labour much greater, but it must be of a far higher and consequently of a more expensive class. Then, as to the accuracy of tension with hoops, its atttainment is almost impracticable, while the process of shrinking on is not to be depended upon. Not only is there a difficulty in insuring the exact temperature required, but scarcely any two pieces of iron will shrink identically; and when the

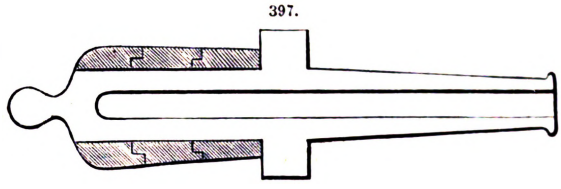
$\frac{1}{100}$ part of an inch of contraction would give rise to a great variation in tension, the necessity of perfect accuracy is apparent. It has been proposed to force the hoops in longitudinal sections by hydrostatic pressure into a gun slightly conical. Captain Blakely, in a lecture given by him at the United Service Institution, in 1859, gave an account of his experiments. His first gun was an 18-pounder, Fig 396, consisting of one series of wrought-iron rings shrunk on a cast-iron cylinder,

396.



5·5 in. in diameter inside, and $1\frac{3}{4}$ in. thick. The wrought-iron rings were from 2 in. thick downwards; the total thickness of the breech was $3\frac{3}{4}$ in., that of the ordinary 18-pounder service-gun being $5\frac{3}{4}$ in. This gun was fired frequently, and stood well. It was then bored out as a 24-pounder; but not being truly bored, the cast iron was reduced on one side to only $\frac{1}{2}$ in. thick. In this state it sustained without injury several hours' firing, with charges varying from one shot and 4 lbs. of powder, to one shot, two wads, and 8 lbs. of powder. At the third round with this latter charge it burst. This gun had a thickness of only 2 5 in. found the charges, as compared with a service 24-pounder 6 in. in thickness.

397.



Capt. Blakely next got a 9-pounder, Fig. 397, turned down from the trunnions to the breech, and on this part he put wrought-iron rings of such a size as to replace the metal removed. This gun was fired, round for round, with a cast-iron service-gun of the same size and weight. The following Table gives the result:—

| No. of Shot. Blakely. | Charge of Powder. | No. of Shot. | No. of Rounds fired. | | No. of Shot Fired from Service-Gun. |
|---|---|---|---|---|---|
| | | | Blakely's. | Service. | |
| | lbs. | | | | |
| 4 | 8 | 2 | 2 | 2 | 4 |
| 86 | 3 | 1 | 86 | 86 | 86 |
| 26 | 4 | 1 | 26 | 26 | 26 |
| 5 | 5 | 1 | 5 | 5 | 5 |
| 10 | 5 | 2 | 5 | 5 | 10 |
| 636 | 6 | 2 | 318 | 110 | Burst 220 |
| 3 | 6 | 3 | 1 | .. | .. |
| 4 | 6 | 4 | 1 | .. | .. |
| 5 | 6 | 5 | 1 | .. | .. |
| 6 | 6 | 6 | 1 | .. | .. |
| 7 | 6 | 7 | 1 | .. | .. |
| 8 | 6 | 8 | 1 | .. | .. |
| 9 | 6 | 9 | 1 | .. | .. |
| 1580 | 6 | 10 | 158 | .. | .. |
| 2389 | .. | .. | 607 | 234 | 351 |

Thus it appears that Captain Blakely's gun stood 607 rounds, and the Government service-gun only 234 rounds; the number of shot thrown being 2389 and 351 respectively, or nearly as 7 to 1.

Proceeding with Longridge's experiments, the first point to be settled is the amount of initial strain to be put on each coil. The formula adopted by Longridge was $t = \mathrm{T} \cdot \frac{x^2 - r^2}{x^2}$.

According to Professor Hart's investigation, the formula is $t = \mathrm{T}\ \mathrm{R}\ \frac{x^2 - r\,y}{x\,(r + y)}$, which, in the case of small wire is nearly $t = \frac{\mathrm{T\,R}}{x} \cdot \frac{x - r}{x + r}$.

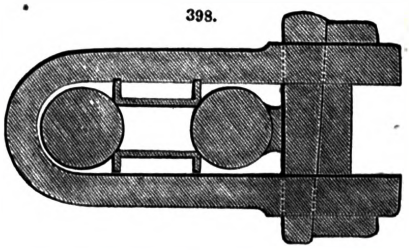
These, however, are general formulæ which require modification, according to the varying circumstances of each case, before they can be applied to practice.

Experiments on cylinders prepared according to the first formula were conducted as follows. A number of brass cylinders were prepared of exactly the same dimensions, namely:—

Internal diameter .. .. .. .. .. .. 1 in.
External „ .. .. .. .. .. .. $1\frac{3}{16}$ in.
Thickness of brass .. .. .. .. .. .. $\frac{3}{32}$ in.

These cylinders were accurately turned and bored, and had a flange $\frac{1}{4}$ in. in depth and $\frac{1}{4}$ in. in thickness, at each end. Each end was widened out, so as to afford seating to two gun-metal balls, which were accurately ground to fit them. The total content of each cylinder, with the balls in their places, was 300 grains of the best sporting-powder. When the powder was put into the cylinder, and the balls were placed at each end, the whole was bound together by a very strong wrought-iron strap, similar to the strap of a connecting-rod, with a jib and cotter. The cotter was driven tightly home, and the powder was then fired through a small touch-hole left in the side-seating, Fig. 398.

398.



The first experiments were to ascertain the effect of the powder on the cylinders, without any wire. They were commenced with charges of powder, beginning at 50 grains, and increasing until the cylinder burst.

The results were as follows:—

| No. of Experiment. | No. of Cylinder. | Condition. | Charge of Powder. | Effect. |
|---|---|---|---|---|
| | | | grains. | |
| 1 | 1 | Without wire | 50 | Slightly bulged. |
| 2 | „ | „ | 60 | Bulged a little more. |
| 3 | „ | „ | 70 | „ „ external diam. $1\frac{5}{16}$. |
| 4 | „ | „ | 80 | „ „ „ $1\frac{7}{16}$. |
| 5 | „ | „ | 90 | Burst. |
| 6 | 2 | Two coils of wire, $\frac{1}{64}$ in. | 90 | No effect. |
| 7 | „ | „ „ one end loose | 100 | Bulged at loose end. |
| 8 | 3 | Without wire | 70 | Bulged to $1\frac{1}{32}$. |
| 9 | 4 | Six coils of $\frac{1}{64}$ wire | 100 | No effect. |
| 10 | „ | „ „ | 110 | „ |
| 11 | „ | „ „ | 120 | „ one end of wire came loose. |
| 12 | „ | Same cylinder, with one coil of $\frac{1}{32}$ wire | 100 | Burst, the end of the wire being badly fastened; wire uninjured. |
| 13 | 5 | Two coils of $\frac{1}{32}$ wire | 100 | No effect. |
| 14 | „ | „ „ | 120 | „ |
| 15 | „ | „ „ | 130 | „ |
| 16 | 6 | Four coils of $\frac{1}{32}$ wire | 120 | „ |
| 17 | „ | „ „ | 130 | „ |
| 18 | „ | „ „ | 140 | „ |
| 19 | „ | „ „ | 150 | „ |
| 20 | „ | „ „ | 160 | „ |
| 21 | „ | „ „ | 170 | „ |
| 22 | „ | „ „ | 180 | „ |
| 23 | „ | „ „ | 200 | „ |

The strength of the wire used in these experiments was ascertained, by trial, to be as resisting a dead tension;—

$\frac{1}{64}$ .. 23 lbs. = 120,000 lbs. the sq. in.
$\frac{1}{32}$ .. 70 lbs. = 92,000 lbs. the sq. in.

If now the expansive force of the powder is taken to be inversely as the volume, its ultimate strength may be approximately arrived at from the last experiment. The powder then could not burst the cylinder. Now the strength of the cylinder, supposing all the material to be equally strained, could not exceed the following to the lineal inch of cylinder:—

| | |
|---|---|
| Wire | 17,920 lbs. |
| Brass | 3,136 „ |
| | 21,056 lbs., or 9·4 tons. |

As the internal diameter was exactly 1 in., it shows that the ultimate force of the material in Experiment 23 did not exceed 9 4 tons the sq. in. Assuming the law as above, the ultimate pressure, supposing the cylinder to have been full, could not exceed $9{\cdot}4 \times \frac{300}{200}$. or 13 tons the sq. in.

The enormous strain to which these cylinders were subjected is evinced by the effects upon the gun-metal balls, which were more or less cut away by the gases where they touched the cylinders.

A subsequent experiment was conducted in the following manner:—

A brass cylinder, Fig. 399, was constructed of nearly the same internal dimensions as a 3-pound mountain-gun, about 3 in. diameter and 36 in. long. The thickness of the brass was $\frac{1}{4}$ in.; at the breech end it was covered with six coils of steel wire, square in section, and of No. 16 wire-

gauge = $\frac{1}{16}$ of an inch. These coils extended about 15 in. along the cylinder, and were reduced towards the muzzle to two coils. Consequently, the thickness of the cylinder was,

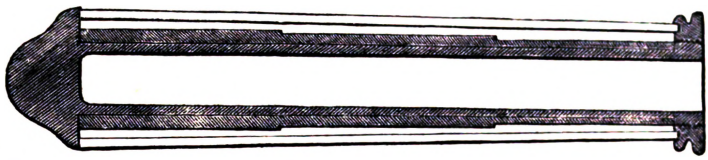
At the breech $\frac{1}{4}$-in. brass + $\frac{3}{8}$-in. iron = $\frac{5}{8}$ in.
„ muzzle $\frac{1}{4}$-in. brass + $\frac{1}{8}$-in. iron = $\frac{3}{8}$ in.

The thickness of the 3-pounder gun, with which it may be compared, being,

At the breech .. .. .. .. .. 2·37 in.
muzzle .. .. .. .. .. 0·75 in.

This cylinder was not mounted as a gun; it had no trunnions; it was cleated with wood; and the object of a deep steel ring, which was screwed on the muzzle, was simply to cover the ends of the cleating. This cleating had nothing to do with the principle involved, and was only used to screen the construction from general observation.

399.



This cylinder was proved with repeated charges, varying from $\frac{1}{2}$ lb. of powder and one round shot, to 1$\frac{1}{2}$ lb. of powder and two shots. The cylinder was simply laid on the ground, with a slight elevation, its breech abutting against a massive stone wall, so as to prevent recoil. It stood the proof without injury. Another trial was made with this gun, before the Committee of Ordnance, in the following manner: —

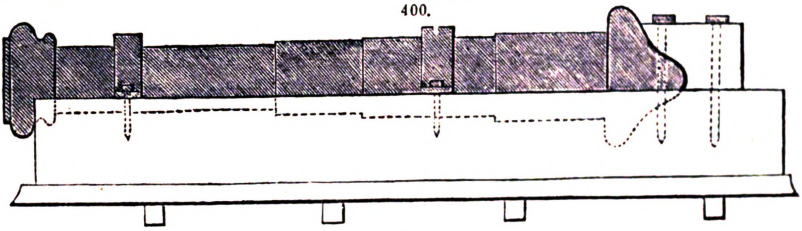
The gun was clamped on a block of oak with iron clamps, and allowed to recoil on a wooden platform. Two rounds were fired; first with a charge of 1 lb. of powder, one shot, fixed to wood bottom, and one wood over the shot; the recoil was 7 ft.; the gun was found to have slightly shifted its position on the block; a trifling expansion of the wire had also taken place at the breech. At the second round the gun was fired with 2 lbs. of powder, one shot, and one wad, and burst; the separation took place about 2 in. in front of the base-ring; the breech was completely separated from the rest of the gun, and was blown 90 yds. directly to the rear. The wire was unravelled to the length of 3 or 4 ft., and the brass cylinder burst in a peculiar manner, turning its ends upwards and outwards. It also opened slightly at the centre of the gun, but the wire did not give way at that point. The ordinary proof-charge for a gun of this diameter would be 1$\frac{1}{4}$-lb. shot and one wad.

In order to try more particularly the effect of the wire in giving strength to the cylinder, this gun was, after bursting, sawn in two at the centre, and one end of each portion was plugged with a brass plug, which was secured in its place by iron bands and several coils of wire: these guns were then secured to slides of wood, as in the former instance; they were placed opposite the proof-butt, and that made from the breech end was loaded with $\frac{1}{2}$ lb. powder, and shot. It burst, the breech being blown out, and the wire uncoiling to a considerable extent.

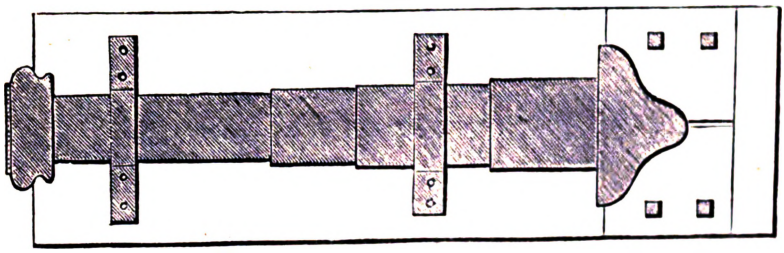
The muzzle portion was then loaded with a similar charge. It did not burst; but was much shaken by the discharge, and portions of the iron bands gave way. It was then loaded with 1 lb. of powder and one shot, which, on discharge, burst in two places, the breech being completely separated from the gun, and the slide on which it had been fired was rent into several pieces.

The bursting of this cylinder was not due to its construction, but to the manner in which it was mounted, shown in Figs. 400, 401.

400.



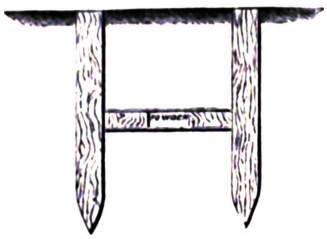
401



Experiments were afterwards made with a piece of the broken cylinder about 2 ft. in length, stripped of all the wire, with the exception of two coils. It was then a brass tube 2 ft. long and

¼ in. thick, with two coils of square steel wire, each $\frac{1}{16}$ in. thick, making together ¼ in. brass and ⅛ in. wire. In the middle of this was placed 1¼ lb. of Government cannon-powder, and the ends were filled with closely-fitting wood plugs, fixed tightly with iron wedges. A trench 3 ft. deep was then dug in stiff clay, and the cylinder laid at the bottom. At each end a railway sleeper was driven firmly into the clay; the trench was then filled in, and the clay well pounded with a heavy beater. The powder was then fired by means of a patent fuse. The whole of this arrangement is shown in Fig. 402. The wooden plugs and sleepers were thrown out with great violence, and a large mass of clay blown out at each end, but the cylinder remained uninjured.

402.

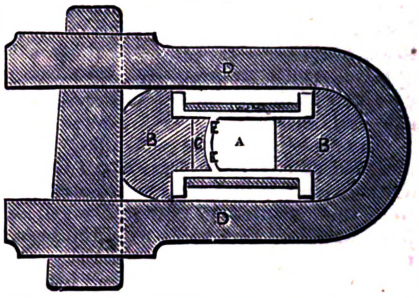


403.

It was, after this, charged with 2 lbs. of powder, the ends filled with closely-fitting iron plugs, and the whole bound together, Fig. 403, by an iron strap of a sectional area of 5 sq. in. The powder was then ignited, and the iron strap torn asunder, but the cylinder remained intact, except at the ends, where, from the wire being imperfectly fastened, it uncoiled, and the cylinder was torn open. Taking the tensile force of the iron strap at 18 tons the square inch, the force of the powder must have been above 13 tons the square inch; yet this was resisted by ¼ in. of brass and ⅛ in. of steel wire.

The diametral strain must have been 39 tons; and, taking the brass at 10 tons the square inch, it leaves 34 tons for the steel wire, which, divided over the two sides, or ¼ in., would give for the ultimate resisting strength of the wire not less than 136 tons the square inch of section. The wire used was of the finest quality.

404.




Further experiments were now instituted; firstly, to try the effect of wire in enabling hard cast iron to resist a bursting strain; secondly, with a view of ascertaining whether it was possible to transmit the force of the powder through a thin breech of cast iron to a yielding substance placed between that breech and the carriage of the gun.

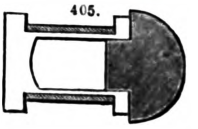
Two sets of cylinders were prepared; the first set arranged as shown in Fig. 404, where A is the powder-chamber; B B, cast-iron plugs; C, the space between the bottom of the powder and the plug B, filled up with a soft material; D, a wrought-iron strap, with jib and cotter for keying up the plugs B B. The object was to ascertain whether the diaphragm at E E would be shattered by the force of the explosion. Six cylinders were thus prepared, and charged with from 50 to 250 grains of Government cannon-powder, the total contents of the cylinder being 310 grains.

The following were the results:—

| No. of Cylinder. | Wire. | Charge. | Results. | Material behind the Diaphragm. |
|---|---|---|---|---|
| | | grains. | | |
| 0 | Two coils .. | 50 | No effect .. .. | Lead. |
| ,, | ,, ,, .. | 50 | ,, .. .. | ,, |
| ,, | ,, ,, .. | 100 | ,, .. .. | ,, |
| ,, | ,, ,, .. | 120 | ,, .. .. | ,, |
| ,, | ,, ,, .. | 150 | Burst .. .. .. | ,, |
| 1 | Four coils .. | 150 | No effect .. .. | ,, |
| ,, | ,, ,, .. | 180 | Top flange burst .. | ,, |
| 3 | Six coils .. | 180 | No effect .. .. | ,, |
| ,, | ,, ,, .. | 200 | ,, .. .. | ,, |
| ,, | ,, ,, .. | 220 | ,, .. .. | ,, |
| ,, | ,, ,, .. | 240 | Flange burst .. .. | ,, |
| 6 | Eight coils .. | 240 | ,, .. .. | ,, |
| 8 | ,, ,, .. | 200 | No effect .. .. | Gutta-percha. |
| ,, | ,, ,, .. | 220 | Burst .. .. .. | Gutta-percha softened by heat. |
| 9 | Ten coils .. | 240 | No effect .. .. | Lead. |
| ,, | ,, ,, .. | 250 | Flange burst. | |

Iron wire, No. 21 gauge, $\frac{1}{25}$ in. diameter, was used; its breaking strain was 60 lbs.
In no case was the bottom of the cylinder injured, except in the second experiment with

cylinder No. 8, when the gutta-percha was softened by the heat of the first explosion. The lead transmitted the force perfectly in every case; showing that there is no practical difficulty in transmitting the force through even so thin a diaphragm as $\frac{1}{16}$ of an inch, even when of so brittle a material as cast iron.




The second set of cylinders, Fig. 405, each contained 305 grains when full to the plug. The plugs fitted accurately, and the powder was fired through a small touch-hole, the size of a pin, with the following results:—

| No. of Cylinder. | Wire. | Charge. | Results. | Remarks. |
|---|---|---|---|---|
| | | grains. | | |
| 0 | None .. .. | 40 | No effect. | |
| ,, | ,, .. .. | 50 | ,, | |
| ,, | ,, .. .. | 60 | ,, | |
| ,, | ,, .. .. | 70 | ,, | |
| ,, | ,, .. .. | 80 | Burst. | |
| 2 | Four coils .. | 130 | No effect. | |
| ,, | ,, ,, .. | 150 | Flange burst. | |
| 7 | Eight coils .. | 200 | No effect .. . | A wrought-iron flange $\frac{1}{4}$ in. deep, contracted on flange. |
| ,, | ,, ,, .. | 220 | ,, | |
| ,, | ,, ,, .. | 240 | ,, | |
| ,, | ,, ,, .. | 250 | ,, | |
| ,, | ,, ,, .. | 260 | ,, | |
| ,, | ,, ,, .. | 270 | ,, | |
| ,, | ,, ,, .. | 280 | ,, | |
| ,, | ,, ,, .. | 290 | ,, .. .. | Hoop on flange shifted. |
| 5 | ,, ,, .. | 200 | ,, | |
| ,, | ,, ,, .. | 220 | ,, | |
| ,, | ,, ,, .. | 230 | ,, | |
| ,, | ,, ,, .. | 240 | .. .. .. .. | Flange cracked. |
| 4 | Four coils .. | 200 | No effect. | |
| ,, | ,, ,, .. | 250 | .. .. .. .. | Flange cracked. |
| 10 | Ten coils .. | 310 | No effect. | |

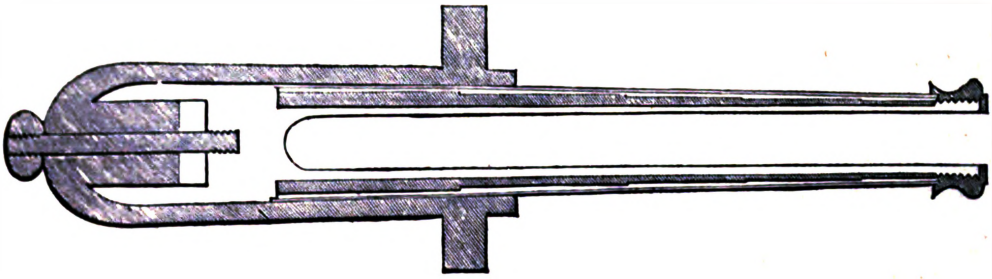
In these experiments the same wire as in the last was used. Its breaking strain was 60lbs.; consequently, the actual strength of the material in the cylinder to the lineal inch was:—

| | | Tons. | Tons. |
|---|---|---|---|
| No. 0. | Cast iron $0{\cdot}10 \times 2 \times$ tons .. .. = | 1·76 | 1·76 |
| | Nil. | | |
| ,, 2. | Cast iron, as above .. .. .. = | 1·76 | |
| | Wire $4 \times 28 \times 2 \times \frac{60}{2240}$ .. .. = | 6 00 | |
| | | | 7·76 |
| ,, 7. | Cast iron, as above .. .. .. = | 1·76 | |
| | Wire $8 \times 28 \times 2 \times \frac{60}{2240}$ .. .. = | 12 10 | |
| | | | 13·76 |
| ,, 5. | Same as No. 7 .. .. .. .. = | .. | 13·76 |
| ,, 4. | ,, ,, 2 .. .. .. .. = | .. | 7 76 |
| ,, 10. | Cast iron .. .. .. .. .. = | 1·76 | |
| | Wire $10 \times 28 \times 2 \times \frac{60}{2240}$ .. .. = | 15·00 | |
| | | | 16·76 |

The enormous force of the expansive gases in these experiments was shown by their action on the plugs, which, although accurately fitted and of hard iron, were chiselled and grooved out in an extraordinary manner; the rents, too, were rapidly enlarged. The results obtained as regards strength were so conclusive, that Longridge proceeded to construct a small gun, represented in Fig. 406. This gun was 2·96 in. in bore, and 36 in. long in the clear; it had on it twelve coils of No. 16 W. G. iron wire at the breech, decreasing to four coils at the muzzle. The thickness of cast iron was $\frac{1}{16}$ in. at the breech and $\frac{1}{2}$ in. at the muzzle. The gun was cast hollow, and a recess left in the thick part of the breech, in which an india-rubber washer, $\frac{3}{4}$ in. thick, was placed. The trunnions formed no part of the gun, but consisted of a strap passing round the breech, with two side-rods extending about one-third the length of the gun, and terminating in the trunnions themselves. Thus the whole force of the recoil was transmitted through the heavy mass at the breech, then through the caoutchouc, and along the side-rods to the trunnions. The whole was mounted on a wood carriage on four roller-wheels, about 8 in. in diameter. The weight of the gun and wrought-iron trunnion-strap was 3 cwt., and the carriage 2 cwt. 0 qr. 15 lbs., making a total

of 5 cwt. 0 qr. 15 lbs. The shot were cast as nearly the size of the bore as possible, so as to move freely, but with very little windage. The spherical shot weighed 3⅛ lbs., and the conical shot

406.



from 6 to 7½ lbs. The following Table exhibits the results of the trial of this gun with 70° elevation, Government cannon-powder being used.

| No. | Description of Shot. | Weight. | — | Charge of Powder. | Range to First Graze. |
|---|---|---|---|---|---|
| | | lbs. | ° | oz. | yds. |
| 9 | Round .. .. | 3⅛ | 7 | 11 | 1400 |
| 4 | Elongated .. | 6½ | 7 | 11 | 1200 |
| 5 | ,, .. | 6 | 7 | 8 | 1220 |
| 6 | ,, .. | 7½ | 7 | 11 | 1542 |
| 8 | ,, .. | 7 | 7 | 11 | Lost beyond 1500 |
| 7 | ,, .. | 7 | 7 | 16 | ,, 1800 |
| 10 | ,, .. | 6½ | 7 | 16 | 1500 |
| 11 | ,, .. | 6½ | 7 | 16 | Lost beyond 1800 |

The variations in range were due, partly, to not having very exact means of adjusting the elevations, and partly to differences in the form of the shot. The trials just described were, moreover only intended as preliminary, it being intended to carry out a more complete series at another time. Unfortunately, this intention was frustrated by an accident which destroyed the gun. Longridge had an idea that it might be possible to obtain more accuracy of flight by using shot somewhat on the principle of an arrow, Fig. 407, with a long, light shaft, and heavy head. The head was of cast iron, and weighed about 8½ lbs.; the shaft was of fir, fitted tightly into the iron head. When fired by mistake with a heavy charge of powder, the wood was driven forward with great force, entering and splitting the iron head. This was wedged so tightly in the chase, that it never left the gun, but tore it asunder about 12 in. from the muzzle. The muzzle with the shot in it were thrown forward about 15 yds., and the wire was uncoiled, but not broken. This accident was due to the action of the shot, and had nothing to do with the principle upon which the gun was constructed. Enough, however, had been done to show that, with a gun weighing only 3 cwt., a shot of 7½lbs. could be thrown from 1500 to 1800 yds., a result, it is believed, not attainable by any 6-pounder in the service.

407.

We now proceed to describe the guns recently adopted by the French navy. These guns are of cast iron, strengthened by steel hoops up to the trunnions, or even a little further on the chase; they are all rifled and breech-loading. The shot used are of two kinds:—1. Oblong, or elongated hollow shot, containing gunpowder and an arrangement for firing it at the moment of impact; 2. Cast steel cylindrical, or cylindrical ogival-headed shot, to be used against iron-clad vessels; the former at short, the latter at long distances. Both kinds of shot are provided with two rows of projections, fitting in the rifled grooves of the gun, and made of zinc, copper, or bronze. The powder-cartridges are made of parchment-paper, while a wad of cork or dry sea-weed is placed between the powder and the projectile. The calibre of these guns is 0·16 m.; 0 19 m.; 0·24 m.; 0·27 m. The following are the chief dimensions of each of these guns:—

*Rifled Gun of* 0·16 *m. Calibre.*

| | |
|---|---|
| Total length .. .. .. .. .. .. | 3·385 m. |
| Diameter at the breech .. .. .. .. | 0·634 m. |
| Diameter of bore .. .. ... .. .. | 0·1647 m. |
| Weight of gun .. .. .. .. .. .. | 5000 kilos. |

The bore is made with three parabolic grooves, the inclination of which varies from 0° at the beginning to 6° at the mouth of the gun. With a charge of 5 kilos. of powder, and elongated projectile weighing 31·5 kilos., and a wad 0·16 m. in length, the range of this gun was as follows:—

| | | | | |
|---|---|---|---|---|
| 950 | mètres, | at an | angle of | 2° |
| 3500 | ,, | ,, | ,, | 10° |
| 7250 | ,, | .. | .. | 35° |

At this last distance the lateral deviation is 16 mètres, and the longitudinal deviation, on an average, 44 mètres. With a charge of 7·5 kilos., and a steel cylindrical, or cylindrical ogival-headed shot weighing 45 kilos., the range of the ogival-headed projectile at 4° was about 1700 mètres; the correctness and length of range were about the same as when the elongated shot and a charge of 5 kilos. were used. The last-mentioned steel shot must not be fired at iron-clad vessels at a greater distance than 600 mètres; but at a distance of 300 mètres this steel shot perforates iron plates of 15 centimètres thickness.

*Rifled Gun of* 0 19 *m. Calibre.*

| | |
|---|---|
| Total length .. .. .. .. .. .. | 3·800 m. |
| Diameter at the breech .. .. .. .. | 0·772 m. |
| Diameter of bore .. .. .. .. .. | 0 194 m. |
| Weight of gun .. .. .. .. .. .. | 8000 kilos. |

The bore is made with five parabolic grooves, the inclination of which varies from 0° at the beginning to 6° at the mouth of the gun. With a charge of 8 kilos., a cast-iron projectile weighing 52 kilos., and a wadding of sea-weed 190 millimètres long, between the powder and shot, the range of this gun was:—

| | | | | |
|---|---|---|---|---|
| 900 | mètres, | at an | angle of | 2° |
| 3300 | ,, | ,, | ,, | 10° |
| 7000 | ,, | ,, | ,, | 35° |

At this last distance the lateral deviation is about 14 mètres, and the average longitudinal deviation about 42 mètres. With a charge of 12·5 kilos., and a cylindrical, or cylindrical ogival-headed projectile weighing 75 kilos., the range of this gun is, under the same angle of inclination, nearly the same for a distance of from 800 to 1000 mètres. The cylindrical projectile is, however, only intended to be fired to a distance of 300 mètres. The solid steel projectiles are formidable weapons against iron-clad vessels covered with armour-plates of 15 centimètres, at distances varying from 300 mètres for the cylindrical and 800 mètres for the cylindrical ogival-headed shot.

*Rifled Gun of* 0·24 *m. Calibre.*

| | |
|---|---|
| Total length .. .. .. .. .. .. | 4·560 m. |
| Diameter of the breech .. .. .. .. | 0·980 m. |
| Diameter of the bore .. .. .. .. .. | 0·240 m. |
| Weight of the gun .. .. .. .. .. | 14,000 kilos. |

The bore is made with five parabolic grooves, the inclination of which varies from 0° to 6°. With a charge of 16 kilos. this gun throws an elongated shot, weighing on an average 100 kilos., as follows:—

| | | | | |
|---|---|---|---|---|
| 1000 | mètres, | at an | angle of | 2° |
| 3600 | ,, | ,, | ,, | 10° |
| 7800 | ,, | ,, | ,, | 35° |

With a charge of 20 kilos. this gun projects a steel cylindrical ogival-headed shot weighing 144 kilos. At an angle of 3° the range is 1120 mètres with the ogival-headed and 1020 mètres with the cylindrical shot. This gun has the greatest effect within 1000 mètres, at which distance a few shots fired from it would destroy the heaviest and strongest walls in existence.

A cylindrical projectile, weighing 144 kilos., fired against a shield constructed of 80 centimètres of wood and armour-plate of 15 centimètres, not only perforated that shield, but also carried with it 140 to 150 kilos. of the iron plate and about a cubic mètre of wood.

*Rifled Gun of* 0·27 *m. Calibre.*

This gun is of the same construction as the three last mentioned,—*viz.* a cast-iron breech-loading gun strengthened by steel hoops. Its dimensions are:—

| | |
|---|---|
| Total length .. .. .. .. .. .. | 4·660 m. |
| Diameter at the breech .. .. .. .. | 1·133 m. |
| Diameter of the bore .. .. .. .. .. | 0·275 m. |
| Weight of gun .. .. .. .. .. .. | 22,000 kilos. |

With a charge of 24 kilos. it throws an elongated projectile weighing 144 kilos.; with a charge of 30 kilos. it throws a solid steel cylindrical, or cylindrical ogival-headed shot weighing 216 kilos.

Two cannons of 42 centimètres calibre were lately cast at Ruelle. The material of which they were composed was cast iron strengthened by steel hoops. These guns weigh each 37,000 kilos.; the diameter of the bore is 0·424 m. The extreme external diameter is 1·360 m.; diameter at the breech, 1·300 m.; diameter at the end of the hooped part, 1 050 m. This gun will throw:—

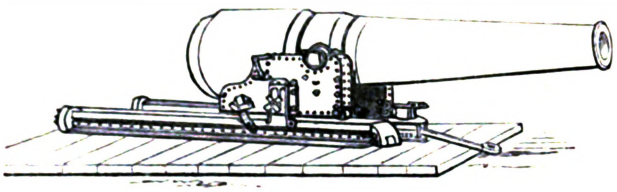
1. A solid spherical shot 0·42 m. diameter, and weighing 300 kilos., with a powder-charge of 50 kilos.

2. A hollow spherical projectile, weighing 210 kilos., containing 9 kilos. of gunpowder, with a charge of 33 kilos.

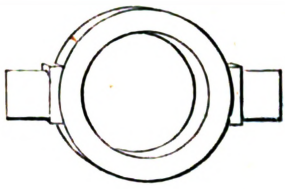
The Fraser gun is made according to Armstrong's system, with bar-iron wound round a solid mandril. This description of gun is made of three different calibres,—9 in., 0·228 m.; 8 in., 0·203 m.; 7 in., 0 177 m. The wrought bar-iron used is submitted to a strain of 21 to 23 tons the square inch; if it does not stand this test, its strength is insufficient; if it is stronger, it becomes too unmanageable. The bars are welded together, after testing, in lengths varying from 50 to 200 ft. = 15 m. to 60 m. These long bars are then placed in a reverberatory furnace, through which they are dragged, as they become sufficiently hot, to be rolled on a mandril; they are then submitted to the blows of a steam-hammer.

Fig. 408 represents the 24-centimètre gun on its carriage.
Fig. 409 the 24-centimètre gun in course of construction and partly hooped.
Fig. 410, hoop with trunnions.
Fig. 411, breech screw and plug for gun of 24 centimètres calibre.

408.



410



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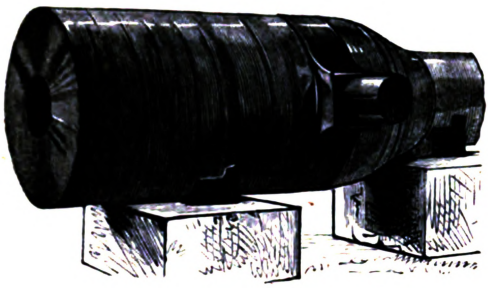

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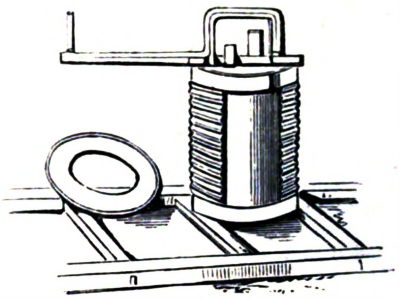
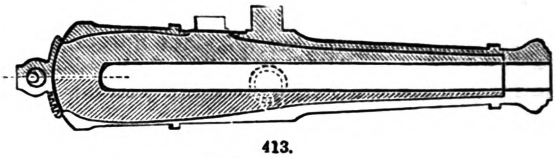


*American Cast-iron Guns.*—Although the United States' Government has made little progress in the adaptation of wrought iron and steel to cannon-making, it has certainly attained to a remarkable degree of perfection in the figure, material, and fabrication of its cast-iron guns. While constructors in Europe have carefully preserved the traditional shapes and ornamentation of early times, shapes that once had a significance, but are now only sources of weakness, the aim in America has been to ascertain the exact amount and locality of *strain*, and to proportion the parts with this reference, to the entire abandonment of whatever is merely fanciful and traditional.

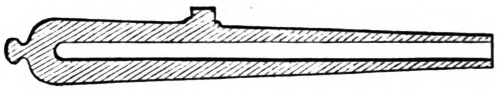
The consequent saving of weight with a given strength at the point of maximum strain, is well illustrated by placing a section of the British 8-in. gun, 68-pounder, over that of the United States' army 8-in. columbiad, Fig. 412.

412

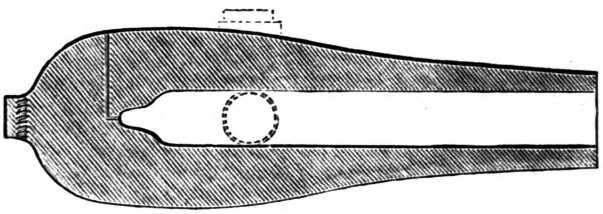


Rodman's process of casting guns hollow and cooling them from within, for the purpose of modifying the initial strains, when added to the advantages of good proportion and strong material, produces nearly or quite the best result attainable with simple cast iron. But the tension of this material at its elastic limit is so low, that it will not alone endure the pressure necessary to give the highest velocities to the heavy projectiles demanded by iron-clad warfare.

413.



414.



Considering, however, the failure of such a large proportion of the heavy wrought-iron guns, both built-up and solid, and the present scarcity and enormous cost of steel masses of the proper quality, it is by no means certain that the cast-iron barrel lined with steel, or, as so largely and successfully used in America, France, and Spain, strengthened by hoops, is not the best temporary resort.

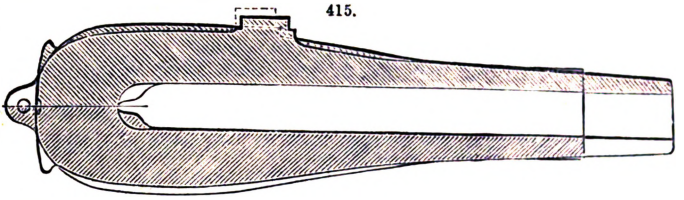
Hollow casting, the most obvious means of improvement, is not deemed important for heavy ordnance alone. The 4 2-in. rifled United States' siege-gun, Fig. 413, is cast hollow and cooled from within. Indeed, the advantages of the process can be better realized in the 8 or 10 in barrel cast for hooping, than in the 15-in. columbiad.

All United States' army guns down to 4 2-in. bore are hollow-cast. The 20-in., 15-in., and 13-in. navy guns have been cast hollow. Fig. 414 shows the 15-in., and Fig. 415 the 13-in. gun.

The following abstract of official reports will explain the conduct and results of the hollow-casting process.

On the 4th of August, 1849, two 8-in. columbiads were cast at the Fort Pitt Works, from the same iron. No. 1 was cast solid, in the usual manner; No. 2 was cast on a hollow core, through which a stream of water passed while the metal was cooling. The iron for both castings was melted at the same time in two air-furnaces, each containing 14,000 lbs. After melting, the liquid iron remained in the furnaces, exposed to a high heat, for one hour; it was then discharged into a common reservoir, whence it issued in a single stream, which, after proceeding a few feet, separated into two branches, one leading to each mould.

415.



The solid casting was cooled as usual in an open pit. The hollow casting was cooled in the interior by passing a stream of water through the core for a period of 40 hours, when the core was withdrawn; after which the water passed through the interior cavity formed by the core, for 20 hours. The average quantity of water passed through during the whole period was 1·66 cubic ft. a minute, or 100 ft. an hour; making in all 6000 cubic ft., weighing 187 tons. The temperature of the water was increased 20° during the 1st hour; 13° during the 20th hour; 8° during the 40th hour; and 3° during the 60th and last hour.. The weight of the water passed through was 30 times the weight of the casting; and the heat imparted by the casting to the water, and carried off by the latter, was equal to 10 ° on the whole quantity of water used. The mould for this casting was placed in a covered pit, which had previously been heated to about 400°; and this heat was kept up as long as the stream of water was supplied. Both columbiads were completed and inspected September 6th, and were found to be accurate and uniform in their dimensions and weights.

The charges used in testing the guns were as follows:—

*Proof Charges.*—1st fire, 12 lbs. powder, 1 ball, and 1 wad; 2nd fire, 15 lbs. powder, 1 shell, and 1 sabot.

*Service Charges.*—10 lbs. powder, 1 ball, and 1 sabot: mean weight of balls used, 63½ lbs.; mean weight of shells used, 49 lbs.; mean proof range of powder used, 298 yds.

The guns were fired alternately, up to the 85th round, at which columbiad No. 1, cast solid, burst. Then the proof proceeded with No. 2, which burst at the 251st round, having endured nearly three times as much service as the other.

In 1851, two more 8-in. columbiads were cast at the same foundry, and under similar circumstances; the one was cast solid, and the other hollow. The iron for both remained in fusion 2½ hours, exposed to a high heat.

The core for the hollow gun was formed upon a water-tight cast-iron tube closed at the lower end. The water descended to the bottom of this tube by a central tube open at the lower end, and ascended through the annular space between the tubes. The water passed through the core at the rate of 2½ cubic ft. a-minute, or 150 ft. an hour. At 25 hours after casting, the core was withdrawn, and the water thereafter circulated through the interior cavity formed by the core, at the same rate for 40 hours; making 65 hours in all. The whole quantity of water passed through the casting was nearly 10,000 cubic ft., weighing about 300 tons, or about 50 times the weight of the casting. The heat imparted by the casting to the water, and carried off by the latter, was equal to 6° on the whole quantity of water used.

A fire was kindled in the bottom of the pit directly after casting, and was continued 60 hours. The pit was covered, and the iron case containing the gun-mould was kept at as high a temperature as it would safely bear, being nearly to a red heat, all the time.

In the same year, two other 10-in. columbiads were cast, of the same iron, the one solid, and the other hollow. Both moulds were placed in the same pit, and all the space in the pit outside of the moulds was filled with moulding-sand, and rammed. This was done because the iron cases of the moulds were not large enough to admit the usual thickness of clay in the walls of the mould. It was apprehended that the heat of the great mass of iron within would penetrate through the thin mould, and heat the iron cases so much as to cause them to yield and let the iron run out of the mould. The external cooling of the 10-in. hollow gun, by the contact of the flask with green sand, was therefore much more rapid than that of the 8-in. hollow gun.

Water was passed through the core at the rate of about 4 cub. ft. a-minute, or 240 ft. an hour, for 94 hours; amounting in all to 22,560 ft., weighing about 700 tons, or 70 times the weight of the casting. The mean elevation of the temperature of all the water passed through the core in 94 hours, was about 3½°. At the end of this period an attempt was made to withdraw the core from the casting, which proved unsuccessful. The contraction of the iron around it held it so firmly, that the upper part of it broke off, leaving the remainder imbedded in the casting. The stream of water was then diminished to about 2 ft. a-minute, which continued to circulate through the core for 48 hours. The supply of water allotted to and circulated through both the 8-in. and 10-in. guns was equal, in weight, to the weight of each casting, in about 1 hour and 20 minutes.

When proving these guns, 80 rounds a-day were easily made with 7 men in 5 hours, from the 8-in. gun; and with 9 men, 60 rounds were made in the same time from the 10-in. gun. 15 rounds were sometimes made from the 8-in. gun in 30 minutes. The two guns making the pair to be

compared were fired alternately, one discharge from each, in regular succession, until one of them burst, when the firing of the survivor was continued by itself. The powder of the cartridges of each pair was of the same proof range, and taken from the same cask.

*Proof Charges.*—8-in., 1st round, 12 lbs. powder, one ball and sabot, and 1 wad; 8-in., 2nd round, 15 lbs. powder, 1 shell with sabot: 10-in., 1st round, 20 lbs. powder, 1 ball and sabot. and 1 wad; 10-in., 2nd round, 24 lbs. powder, 1 shell with sabot.

*Service Charges.*—8-in., 10 lbs. powder, 1 ball with sabot; 10-in., 18 lbs. powder, 1 ball with sabot. Weight of 8-in. balls, 63½ lbs.; of shells, 48½ lbs.: weight of 10-in. balls, 124 lbs.; of shells, 91 lbs.

The number of rounds fired from each gun, including proof charges, were as follows:—8-in. gun, No. 3, cast solid, 73 rounds; 8-in. gun, No. 4, cast hollow, 1500 rounds: 10-in. gun, No. 5, cast solid, 20 rounds; 10-in. gun, No. 6, cast hollow, 249 rounds.

Each of them, excepting the 8-in. gun, No. 4, cast hollow, burst at the last round; and that remains unbroken, and apparently capable of much further service.

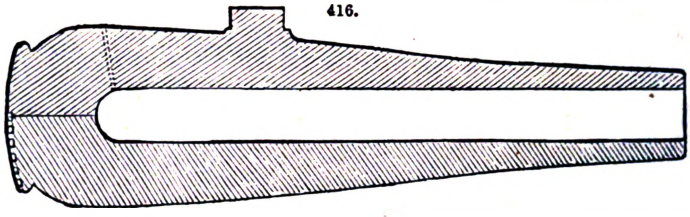
On comparing the enlargements of the bores, made by an equal number of rounds of the guns cast solid with those cast hollow, it will be seen that, in both pairs of guns, the enlargement is least in those cast hollow.

The less endurance of the 10-in. hollow gun than that of the 8-in. hollow one, is accounted for by the fact that the 10-in. gun had no fire on the exterior of the flask while cooling, it having been rammed up in the pit, where it was supposed, at the time of casting, the heat of the gun would have been retained by the sand until the interior should have been cooled by the circulation of water through the core-barrel. This supposition was found to be erroneous on digging out the sand, as its temperature was found to be much lower than had been expected.

One of the 15-in. American naval guns was fired 900 times at elevations from 0 to 5°. The charge commenced at 35 lbs. It was then increased to 50 lbs. With 60 lbs., 220 rounds were fired. The gun at length burst with 70 lbs. The shot in all cases was 440 lbs. After the first 300 rounds, the chamber, Fig. 414, was bored out to a nearly parabolic form, and the chase was turned down 3 in., so as to fit the port designed for the 13-in. gun.

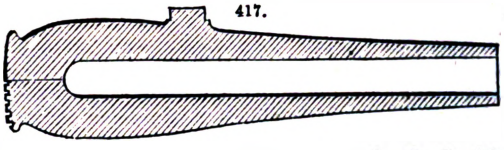
*Columbiads.*—The columbiads, Figs. 416, 417, are a species of sea-coast cannon, which combine certain qualities of the gun, howitzer, and mortar; in other words, they are long, chambered pieces, capable of projecting solid shot and shells, with heavy charges of powder, at high angles of elevation, and are therefore equally suited to the defence of narrow channels and distant roadsteads.

416.



The columbiad was invented by Bumford, and used in the war of 1812 for firing solid shot. In 1844 the model was changed, by lengthening the bore and increasing the weight of metal, to enable it to endure the increased charge of powder, or ⅛th of the weight of the solid shot. Six years after this, it was discovered that the pieces thus altered did not always possess the requisite strength. In 1858 they were degraded to the rank of shell guns, to be fired with diminished charges of powder, and their places supplied with pieces of improved model.

417.



The changes made in forming the new model, consisted in giving greater thickness of metal in the prolongation of the axis of the bore, which was done by diminishing the length of the bore itself; in substituting a hemispherical bottom to the bore and removing the cylindrical chamber; in removing the swell of the muzzle and base ring; and in rounding off the corner of the breech. The present model, as illustrated, was proposed by Rodman, in 1860.

In addition to the heavy ordnance before mentioned, the Navy Department has introduced a superior gun of 10-in. calibre, called a 125-pounder. The exterior dimensions are nearly the same as those of the 11-in. gun, except that the maximum diameter of the reinforce is continued farther forward, 3 calibres. The first of these guns was cast solid, and endured 47 lbs. of powder and 125-lb. balls for some hundred rounds. The new 10-in. un is cast hollow; charge, 40 lbs.; shot, 125 lbs.

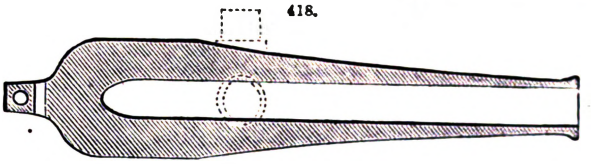
The chambers of the Navy 13 and 15 in. guns, as shown in Figs. 414, 415, have recently been changed to a shape nearly parabolic.

The Navy Department has four 12-in. rifles, cast hollow, of about the exterior dimensions of the 15-in. gun. It is believed that they will have satisfactory endurance with 50-lb. charges and 600-lb. bolts.

Twenty-inch guns for the army and navy have recently been cast at Pittsburg. The following are the particulars of the metal and the fabrication of the first 20-in. army gun:—

The iron was high No. 2, warm blast, 200° hematite, from Blair county, Pennsylvania. The smelted pigs were remelted and cast into pigs, which were again melted in three air-furnaces. The weight of iron was 172,000 lbs.; the time of melting, 7¼ hours; the time of casting, 23 minutes. Water, run through the core at the rate of 30 gallons a-minute, during the first hour was heated from 36° to 92°; during the second hour, at the rate of 60 gallons a-minute, water emerged at 61°. From the 15th to the 20th hour after casting, the water was heated 21·5°. After the 26th hour the core-barrel was removed, and air was forced into the bore at the rate of 2000 cubic feet

a-minute. The metal was considered too high to be cooled by the direct contact of water. At the 50th hour after casting, the air emerging from the gun was 130 seconds in rising, 60° to 212°. The gun was cast on the 11th of February, 1864. On the 17th, the difference in the temperature of the entering and emerging air was 100°; on the 20th it was 33°. Air circulated through the bore till the 24th.




The mould, 5 to 6 in. in thickness, was made in a two-part iron flask, 1½ in. thick. On the 23rd the upper part of the mould was removed; on the 24th the lower part was removed; on the 25th the gun was removed from the pit.

The density of the metal taken from the casting was 7·3028. The tenacity was 28,737 lbs. per square in.

Fig. 418 shows a section of the 11-in. Dahlgren gun used in the United States' navy.

PARTICULARS AND CHARGES OF U. S. HOLLOW-CAST IRON ARMY ORDNANCE.

*The Heavy Guns have no Preponderance.*

| Name of Gun. | Length. | Length of bore. | Max. diam. | Weight. | Service charge. | Bursting charge Shell. | Weight of Shot | Weight of Shell | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| *Smooth-bores.* | in. | in. | in. | lbs. | lbs. | lbs. | lbs. | lbs. | |
| 20-in. columbiad .. | 243·5 | 210 | 64 | 115,200 | 100 | .. | 1000 | .. | Weight of shell not determined. |
| 15-in. „ | 190 | 165 | 48 | 49,100 | 50 / 6 grain | 17 | 440 / 425 | 330 | Cored shot. |
| 13-in. „ | 177·6 | 155·94 | 41·6 | 32,731 | 30 No. 5 | 7 | 300 / 2·0 | 224 | |
| 10-in. „ of 1860 | 136·66 | 105·5 | 32· | 15,059 | 15 for shell / 18 for shot | 3 | 127½ | 100 | |
| 8-in. „ „ | 123·5 | 110 | 25·6 | 8,465 | 10 | 1½ | 68 | 48 | |
| *Rifles.* | | | | | | | | | |
| 4½-in. siege-gun of 1860 .. .. .. | 133 | 120 | 16 | 3,450 | 3½ | .. | 30 | 30 | Twist uniform. 1 turn in 15 ft. Preponderance 300 lbs. |
| 3-in. field-gun of 1861 .. .. .. | 72·65 | 65 | 9·7 | 830 | 1 | .. | 10 | 10 | Twist uniform. 1 turn in 10 ft. Preponderance 40 lbs. |

PARTICULARS AND CHARGES OF U. S. CAST-IRON NAVY ORDNANCE IN SERVICE.

| Name of Gun. | Length of bore. | Max. diam. | Weight. | Service charge. | Max. charge. | Weight of Shot. | Weight of Shell. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | in. | in. | lbs. | lbs. | lbs. | lbs. | lbs | |
| *Smooth-bores.* | | | | | | | | |
| 20-in. gun .. | 163 | 64 | 100,000 | Probably 100 | .. | 1000 | .. | Shell not determined. Cored shot, and gun cast hollow. |
| 15-in. „ .. | 130 | 48 | 42,000 | 35 | 60 | 400 | 330 | Cast hollow. Cored shot. |
| 13-in. „ .. | 130 | 44 7 | 36,000 | 40 | .. | 280 | 224 | Cast hollow. |
| 11-in. „ .. | 132 | 32 | 16,000 | 15 | 20 | 170 | 130 | Lately cast hollow. |
| 10-in. „ .. | 119⅓ | 29 1 | 12,000 | 12½ | 16 | 125 | 100 | Cast solid. |
| 9-in. „ .. | 107 | 72·2 | 9,200 | 10 | 13 | 93 | 70 | Cast solid. |
| 125-pdr. (10-in.) | 117¾ | 33 25 | 16,500 | 40 | .. | 125 | 100 | Cast hollow. |
| *Rifles.* | | | | | | | | |
| Parrott 10-in. .. | 144 | 40 | 26,500 | 25 | .. | 230 to 250 | 250 | The Parrott guns are hooped with wrought iron, and are lately cast hollow. |
| „ 8-in. .. | 136 | 32 | 16,300 | 16 | .. | 132 to 175 | 152 to 175 | |
| „ 100-pdr. (6·4-in.) .. | 130 | 25·9 | 9,700 | 10 | .. | 70 to 100 | 100 | |

*Bronze Guns.*—An alloy of about 90 parts of copper and 10 parts of tin, commonly known as "gun-metal" in Europe, is popularly called "brass" in America, when used for cannon, and named "bronze" by recent American writers. A strong cast iron is also known in America as "gun-metal."

The "work done" in stretching to the elastic limit and to the point of fracture, is less for ordinary bronze than for wrought iron of maximum ductility, and for low steel. This defect, added to the costliness of bronze, to the various embarrassments experienced in the casting of large masses, to its softness, and consequently rapid wear and compression, and to its injury by heat, has

not warranted its employment for large calibres and high charges. The increase of cost, with increase of weight, would probably be greater for bronze than for cast iron, and much greater than for steel or wrought iron, because bronze must be cast under great pressure, to be sound and tenacious. So that, were it the proper metal in other particulars, an unnecessarily large and actually immense non-paying capital would be tied up in a national bronze armament. The high value of the old material would not offset this cost to the extent that it does in railway matters, for obvious reasons.

The mean ultimate cohesion of gun-metal, according to European authorities and the experiments of the United States' Government, is about 33,000 lbs. per sq. in. Mallet states it from 32,334 lbs. to 43,536 lbs. Major Wade states it from 17,698 lbs. to 56,786 lbs.

Benton says, that "the density and tenacity of bronze, when cast into the form of cannon, are found to depend upon the pressure and mode of cooling. This is exhibited by the means of observations made on five guns cast at the Chicopee Foundry, namely:—

| Density. | | | Tenacity per Square Inch. | |
|---|---|---|---|---|
| Breech square. | Gun-head. | Finished gun. | Breech square. | Gun-head. |
| 8·765 | 8·444 | 8 740 | 46,509 | 27,415 |

The guns were cast in a vertical position, with the breech square at the bottom. In consequence of the difference in the fusibility of tin and copper, the perfection of the alloy depends much on the nature of the furnace and the treatment of the melted metal. By these means alone, the tenacity of bronze has been carried, at the Washington Navy Yard Foundry, as high as 60,000 lbs.

The fabrication of bronze ordnance appears to be far better understood in Spain, and more especially in Turkey, than in America or England. Some bronze guns of 20 tons weight have been cast in Spain, but they cannot be rapidly fired.

According to American and British authorities, the want of uniformity, even in different parts of the same gun, is a striking defect. For instance, for light pieces, especially for field-cannon, bronze is much used, but there are many objections even to this alloy. As the tin is much more fusible than the copper, and must be introduced when the latter is in fusion, it is difficult to seize the precise moment when the alloy can be properly formed: part of the tin is frequently burned and converted into scoria.

Major Wade, after calculating the results of experiments on a lot of bronze guns, cast at Chicopee, says, "The most remarkable feature of the above table is the irregular and heterogeneous character of the results which it exhibits in samples taken from different parts of the same guns. By an examination of the results obtained from the heads of all the guns cast, it will appear that the density varies from 8 308 to 8 756, a difference equal to 28 lbs. in the cubic foot; and that the tenacity varies from 23,529 to 35,484, a difference in the ratio of 2 to 3. These differences occur in samples taken from the same part of different castings, the gun-head; the part which, in iron cannon, gives a correct measure of the quality of the metal in all parts of the gun. The materials used in all these castings were of the same quality: they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects. The causes why such irregular and unequal results were produced, when the materials used and the treatment of them were apparently equal, are yet to be ascertained."

The authorities generally agree that the tin in bronze guns is gradually melted by the heat of successive explosions. If this is the case with field-guns, the heavy charges and projectiles, and the quick firing demanded in iron-clad warfare, would soon destroy this material. Colonel Wilford stated, at a meeting of the United Service Institution, that iron mortars were introduced because holes were burned in the chambers of bronze mortars by the immense heat of the powder-gas. Heat also causes the drooping of the parts of a bronze gun that overhang the trunnions.

As to decomposition, Captain Benton says, "Bronze is but slightly corroded by the action of the gases evolved from gunpowder, or by atmospheric causes" but Captain Simpson remarks, that the gases produced by the combustion of gunpowder also produce an injurious effect upon this kind of piece, by acting chemically on the bronze.

All these defects of bronze for the bore of a gun, irrespective of strength, namely, the melting of the tin, the change of figure, the conversion, abrasion, and compression, obviously aggravate each other; and, when taken in connection with rifling and excessive pressures, are conclusive evidence as to the unfitness of the material to meet the conditions of greatest effect under consideration.

The average ultimate tenacity of bronze is so low—in fact, little above that of the best average cast gun-iron—that the loss of strength, due to want of regulated initial tension and compression, becomes a very serious defect when calibres are large and pressure high. To remedy it by hooping bronze with steel or iron, would not avoid the defective surface of the bore just considered.

The Dutch, however, have lined cast-iron guns with bronze, and Blakely has constructed some experimental guns in the same way for another reason: bronze can safely elongate more than cast iron, without permanent change of figure, and when it is put in a position where it must be more elongated by internal pressure, the strength of the whole structure is thus brought into service—the principle of varying elasticity, already considered, is approximately realized.

Bronze hoops upon steel or iron barrels would avoid the defect of a soft bore, but they would increase the defect just considered, due to the unequal stretching of the layers of a tube by internal pressure. A principal advantage of bronze hoops is, that with the little heat they would get from the powder, they would expand to the same extent, approximately, as the more highly-heated iron barrel, thus reducing the danger of bursting by rapid firing.

*Other Alloys.*—Phosphorus is known to improve the strength of copper, and to make it cast soundly. Abel, chemist to the British War Department, stated before the Institution of Civil Engineers, that he had made some experiments upon the combinations of phosphorus with copper, and "had found that by the introduction of a small proportion, say from 2 to 4 per cent., of phosphorus into copper, a metal was produced remarkable for its density and tenacity, and superior in every respect to ordinary gun-metal. He believed the average strain borne by gun-metal might be represented by 31,000 lbs. upon the square inch; whilst the material obtained by adding phosphorus to copper bore a strain of from 48,000 to 50,000 lbs. But the increased tenacity was not the only beneficial result obtained by this treatment of copper. The material was more uniform throughout, which was scarcely ever the case with gun-metal. The experiments alluded to were merely preliminary, and had been, to a certain extent, checked by the improvements since introduced in the construction of field-guns, which had led to a discontinuance of the employment of gun-metal."

*Aluminium* has been found to add great strength to copper. The compound formed of these two metals is called Aluminium Bronze. John Anderson, superintendent of the Royal Gun-factory, Woolwich, found the tensile strength of an alloy of 90 per cent. of copper and 10 per cent. of aluminium was 73,181 lbs. the square in., or twice that of gun-metal, and its resistance to crushing 132,146 lbs., that of gun-metal being 120,000 lbs. The aluminium bronze did not begin to change its form until the pressure exceeded 20,384 lbs. In transverse strength or rigidity it was also found superior to gun-metal, in the ratio of 44 to 1. Its tenacity and elasticity depend on a particular number of meltings: at the first melting aluminium bronze is very brittle, a state to which it again returns after fusion.

The first melting appears to produce an internal mechanical mixture, rather than a chemical combination of the metals; as, in the proportion of 10 of aluminium and 90 of copper, an alloy of a very brittle character is produced by the first melting; but by repeated meltings a more uniform combination seems to take place, and a metal is produced free from brittleness, and having about the same hardness as iron. The alloy, containing rather less than 10 per cent. of aluminium, is said to possess the most uniform composition and the best degree of hardness; but it is not always an easy thing to produce this desirable uniformity of texture, as patches of extreme hardness sometimes occur, which resist the tools, and are altogether intractable to the action of the rollers.

Aluminium bronze, composed of 9 parts by weight of copper and 1 of aluminium, was found by J. Anderson to have a tensile strength of about 43 tons, 96,320 lbs.; but two other specimens, which were not quite sound, had only a mean tensile strength of 22½ tons, 50,400 lbs. So that the metal is liable to great variations in strength.

The cost of this alloy would of course prevent its extensive introduction as a cannon-metal.

*Sterro-metal*, a recent invention of Baron de Rosthorn, of Vienna, is described by a correspondent of the 'Times.' The mechanical properties of the alloy were carefully examined at the Polytechnic Institution, Vienna, with the following results:—

TENSILE STRENGTH OF STERRO-METAL.

| | Tensile Strength, in Tons. | Reduced to Pounds. |
|---|---|---|
| *Sterro-Metal.* | | |
| After simple fusion .. .. .. .. | 27 | 60,480 |
| „ forging red-hot .. .. .. | 34 | 76,160 |
| „ drawn cold .. .. .. .. | 38 | 85,120 |
| *Gun-Metal—Bronze.* | | |
| After simple fusion .. .. .. .. | 18 | 40,320 |

The same copper, from Boston, U.S., was used in making both the sterro-metal and the gun-metal, and for the latter the best English tin was employed. Both alloys were cast under precisely similar conditions, and run into the same mould. Similar tests were made at the Arsenal, Vienna, and the results are as follows:—

TENSILE STRENGTH OF STERRO-METAL.

| | Tensile Strength, in Tons. | Reduced to Pounds. |
|---|---|---|
| *Sterro-Metal.* | | |
| After simple fusion .. .. .. .. | 28 | 62,720 |
| „ forging red-hot .. .. .. | 32 | 71,680 |
| Drawn cold and reduced from 100 to 77 of transverse sectional area | 37 | 82,880 |

The specimens of metal operated on in the preceding experiments were analyzed at the Austrian mint. The results are as under:—

| | Polytechnic Metal. | Arsenal Metal. |
|---|---|---|
| Copper .. .. .. | 55·04 | 57·63 |
| Spelter .. .. .. | 42·36 | 40·22 |
| Iron .. .. .. .. | 1·77 | 1·86 |
| Tin .. .. .. .. | 0·83 | 0·15 |
| | 100·00 | 99·86 |

Experience has shown that the proportion of spelter may vary from 38 to 42 per cent., without materially affecting the quality of the alloy. The specific gravity of the forged metal is 8·37, and that of the same metal, drawn cold into wire, 8·40. But sterro-metal possesses another quality, which, in reference to its application for guns, is regarded as more important than its high tenacity, namely, great elasticity. It is not permanently elongated until stretched beyond $\frac{1}{800}$ of its length. Sterro-metal, it should be stated, is from 30 to 40 per cent. cheaper than gun-metal. Field-guns, from 4 to 12 pounders, have been made of single pieces of metal, worked by the action of a hydraulic press, whereby expense in forging is avoided; but reliable experiments have demonstrated that the metal thus treated has precisely the same properties and the same tensile strength as bars of it drawn out under the steam-hammer.

The following is the official report of experiments made by John Anderson, upon this metal, variously compounded and treated:—

Composition of this alloy, as made in the Arsenal at Vienna, is,—copper, 60; zinc, 41·88; iron, 1·94; tin ·156. And, as made at the Polytechnic, Vienna, its composition is,—copper, 60; zinc, 46·18; iron, 1·93; tin, ·905.

Alloys of similar composition to that of the Austrian metal have been prepared in the Royal Gun-factories, from which a better result has been obtained than from mixtures of the Austrian metals, also prepared in the Royal Gun-factories. The subjoined Table shows the results of the experiments with these different specimens.

This alloy is said to be the invention of Baron de Rosthorn, of Vienna. It derives its name from a Greek word signifying "firm." It consists of copper and spelter, with small portions of iron and tin; and to these latter its peculiar properties are attributed.

It has a brass-yellow colour, is close in grain, is free from porosity, and has considerable hardness, whereby it is well adapted to bearing-metal, or other purposes, where resistance to friction is needed.

The inventor proposes that, in heavy ordnance, the interior should consist of a tube of sterro-metal, and, over this, wrought or cast iron should be shrunk, from the breech to beyond the trunnions.

Composition and Strength of Sterro-Metal, Woolwich.

| Composition | Treatment. | Strain at Permanent Elongation of ·002 the inch. | Breaking Weight. | Ultimate Elongation the inch. |
|---|---|---|---|---|
| | | tons. | tons. | inch. |
| Austrian mixture .. .. .. .. .. | As received .. | 6·75 | 26·75 | ·1 |
| R. G. factories' mixture of copper, 60; zinc, 39; iron, 3; tin, 1·5 .. .. .. | Cast in sand .. | 11· | 21·5 | ·05 |
| R. G. factories' mixture of copper, 60; zinc, 44; iron, 4; tin, 2 .. .. .. | " .. .. | 13·75 | 19·25 | ·015 |
| " " " .. .. | Cast in iron .. | 17·25 | 24·25 | ·016 |
| " " " .. .. | Cast in iron and annealed .. .. | 15·25 | 23·25 | ·02 |
| " " " .. .. | Forged red-hot .. | 17· | 28· | ·045 |

In a discussion before the Institution of Civil Engineers, Charles Fox said that "he believed it would eventually be found that the best gun could be constructed with some extremely dense and homogeneous alloy, cast and used without being drawn under the hammer. If a gun was made of an alloy possessing very great density, the detonating force of the powder would be resisted by a greater quantity of the metal employed than it could be by making use of one with greater elasticity. He thought, therefore, the best guns would be made of iron, mixed with some other metals, such as wolfram and titanium, so as to insure the greatest strength and density. Mushet had obtained great density, by mixing with iron a small percentage of wolfram, and great strength by the use of titanium. Therefore, he was inclined to believe, that guns cast of the densest alloys would have greater effect, in proportion to their thickness, than could be obtained by any complicated and expensive mode of construction."

It is obviously impossible, in the absence of further experiments, to predict either great success or failure for the alloys considered, as compared with steel. The field for discovery and improvement is certainly broad and promising; but no more so than in the case of steel. Although the alloying of copper, especially for cannon, has been practised for more than five hundred years, and

should, therefore, be in advance of steel-making, which, for the purposes of artillery, is the work of the last decade, both metals—in fact, all metals—are undeveloped, because their chemical relations, and especially their elongation, within and beyond the elastic limit, and the corresponding pressures, have not been properly investigated.

While certain alloys, of both iron and copper, have one important feature in common—homogeneity, due to fusibility, at practicable temperatures—the alloys of iron have this grand advantage; iron is everywhere cheap and abundant; and the other necessary ingredients and fluxes—carbon, manganese, zinc, and silicium—are equally abundant, and, in some localities, already mixed, which would appear to be, on the whole, advantageous, although the mixtures are not found in proper proportions.

The fitness of metals for cannon depends chiefly on the amount of their elongation within the elastic limit, and the amount of pressure required to produce this elongation; that is to say, upon their elasticity.

It also depends, if the least possible weight is to be combined with the greatest possible preventive against explosive bursting, upon the amount of elongation and the corresponding pressure, beyond the elastic limit; that is to say, upon the ductility of the metal.

Hardness, to resist compression and wear, is the other most important quality.

Cast iron has the least ultimate tenacity, elasticity, and ductility; but it is harder than bronze and wrought iron, and more uniform and trustworthy than wrought iron, because it is homogeneous.

The unequal cooling of solid castings leaves them under initial rupturing strains; but hollow casting, and cooling from within, remedies this defect, and other minor defects.

Wrought iron has the advantage of a considerable amount of elasticity, a high degree of ductility, and a greater ultimate tenacity, than cast iron; but, as large masses must be welded up from small pieces, this tenacity cannot be depended upon: this defect, however, is more in the process of fabrication than in the material, and may be modified by improved processes. Another serious defect of wrought iron is its softness, and consequent yielding, under pressure and friction.

Low cast steel has the greatest ultimate tenacity and hardness: and, what is more important, with an equal degree of ductility, it has the highest elasticity.

It has the great advantage over wrought iron, of homogeneity, in masses of any size.

It is, unlike the other metals, capable of great variation in density, by the simple processes of hardening and annealing, and, therefore, of being adapted to the different degrees of elongation that it is subjected to, in either solid or built-up guns.

Bronze has greater ultimate tenacity than cast iron, but it has little more elasticity, and less homogeneity; it has a high degree of ductility, but it is the softest of cannon-metals, and is injuriously affected by the heat of high charges.

The other alloys of copper are very costly, and their endurance, under high charges, is not determined.

In view of the duty demanded of modern guns, simple cast iron is too weak, although it can be used to advantage for jackets over steel tubes—a position where mass, small extensibility, and the cheap application of the trunnions and other projections, are the chief requirements. And, although cast-iron barrels, hooped with the best high wrought iron, and with low steel, cannot fulfil all the theoretical conditions of strength, and do not endure the highest charges, they have thus far proved trustworthy and efficient.

Wrought iron, in large masses, cannot be trusted, and is, in all cases, too soft.

Bronze is soft, and destructible by heat.

Low steel is, therefore, possibly in connection with cast iron, as stated above, by reason of the associated qualities which may be called strength and toughness, the only material from which we can hope to maintain resistance to the high pressures demanded in modern warfare.

See ARMOUR. GUNPOWDER. MATERIALS OF CONSTRUCTION, *strength of.*

*Works relating to this subject:*—Struensee, 'Aufangsgründe v. Artillerie,' 1788. Meineke, 'Anleitung zum Guss des Bronzirten Geschützes,' 1817. 'Report of Experiments on the Strength and other Properties of Metals for Cannon,' 4to, Philadelphia, 1856. R. Mallet, 'On the Construction of Artillery,' 4to, 1856. 'Report of Experiments upon British and Foreign Ores for the Purposes of Cast-Iron Ordnance,' fol., 1859. J. A. Longridge, 'On the Construction of Artillery,' Transactions Inst. C. E., 1860. Captain Rodman's 'Reports of Experiments on the Properties of Metals for Cannon,' 4to, Boston, 1861. 'Reports from the Select Committee on Ordnance,' 1862–63. D. Treadwell, 'On the Construction of Hooped Cannon,' royal 8vo, New York, 1864. Holley's 'Treatise on Ordnance and Armour,' 8vo, New York, 1865. Aloncle, 'Études sur l'Artillerie,' 8vo, Paris, 1866. 'Reports of the Whitworth and Armstrong Committee,' 2 vols., fol., 1866. H. L. Abbott, 'Siege Artillery in the Campaigns against Richmond,' 8vo, New York, 1868.

See also:—'Journal of the United Service Institution.' 'Aide-Mémoire to the Military Sciences.'

ASHLERING. FR., *Maçonnerie de moëllon;* GER., *Schalwerk, Bruchstein Mauerwerk;* ITAL., *Ritti;* SPAN., *Obra de silleria y sillarejo.*

419.

Ashlering, in carpentry, are the short, upright pieces of timber or quartering, as A in sketch, fixed in *garrets* to the *floor* and *rafters* to cut off the acute angle formed by the rafters and floor. They are usually 2½ in. thick by 4 in. wide, and from 2½ to 3 ft. long, spaced about 12 in. apart. They are lathed over and plastered as in ordinary *partitions.*

*Ashlar or Ashler Work.*—In masonry, where each stone is squared and dressed to given dimensions. It is usually applied to the squared stone-facing of walls in which the beds are dressed horizontal and the joints vertical and disposed at uniform distances, so as to break joint with the stone in the course above and below. The face may be worked in any way. It may be

left rough from the quarry, when it is called "rock-ashlar;" or it may be dressed in a variety of ways, in which case it is called "dressed ashlar."

In the neighbourhood of London, the term ashlar is applied to a thin facing of squared stones laid in courses, with close-fitting joints, and set in fine mortar or putty. See MASONRY.

ASH-PAN. FR., *Cendrier;* GER., *Aschkasten;* ITAL., *Ceneracciolo;* SPAN., *Cenicero*

See BOILERS.

ASH-PIT. FR., *Fosse à cendre;* GER., *Aschloch;* ITAL., *Cenerario;* SPAN., *Cenicero.*

See BOILERS.

ASPHALTE. FR., *Asphalte;* GER., *Asphalt;* ITAL., *Asfalto;* SPAN., *Asfalto.*

Asphalte is a bituminous limestone found in the Jura Mountains and other localities, which is used in the formation of pavements and in the manufacture of bituminous cement.

Bitumen is found in nature in various conditions, and is met with in many parts of the world. It is supposed to be the substance mentioned in Genesis, chap. xi., ver. 3, as having been used, instead of mortar, in building the Tower of Babel; and there are numerous proofs of its having been used in ancient buildings in Egypt and Assyria. It is found, more or less pure, in large quantities washed on the shores from the surface of the Dead Sea or Lake Asphaltites, and is supposed to be derived from bituminous springs in the neighbourhood of that lake. Immense quantities of bitumen exist in the island of Trinidad, at a place called the Tar Lake, where the ground, for an unknown depth, contains so large a proportion of bitumen, that in hot weather it becomes too soft to walk upon. In some localities there are beds of shale so highly impregnated, that upon wells or pits being dug they become filled with bitumen. In other localities there are bituminous sands. In Auvergne, in France, are many beds of this description; and near Clermont bitumen exudes from the ground into a kind of wells, which have received the name of Fountain of Pitch.

It is, however, from beds of bituminous sandstone that, next to the bituminous limestone, the best description of bitumen is obtained. It is from these beds, which have been technically termed molasses, that most of the bitumen, or mineral tar, is obtained for mixing with the bituminous limestone in the manufacture of asphaltic mastic.

Bitumen is composed of carbon, hydrogen, and oxygen, in the proportion of about 85 carbon, 12 hydrogen, and 3 oxygen. The colour is a deep black, with a very slight tinge of redness. It has a peculiar aromatic odour, somewhat resembling, but still very different from that of tar and pitch. The odour is very strong when at a boiling temperature, but at ordinary temperatures it is scarcely perceptible. At a temperature under 50° Fahrenheit it is solid and brittle; from 50° to about 70° it is soft and plastic; from 70° to 90° it has a pasty consistence; from 90° to 110° or 120° it is glutinous; and above 120° it is liquid. The specific gravity is about 1·03.

The geological origin of bitumen is somewhat uncertain. The most probable hypothesis appears to be that it was produced from beds of coal while subject to heat and pressure at great depths below the surface of the earth, and that it was afterwards forced upwards through the superincumbent strata during some convulsions of nature. In its progress to, or on its arrival at the surface, it impregnated the limestone and sandstone rocks, and became mixed with the other strata in which it is now found. Here it may be necessary to observe, that the vague conjectures upon which geology is founded, and such matter as rest rather upon a speculative than a substantial, philosophical basis, are neither examined nor discussed in this work, and they receive but little of our attention.

For the purpose of obtaining bitumen, or mineral tar, the sandstone is broken into pieces about the size of the stones used for macadamizing roads, and placed in caldrons and boiled in water. In about an hour the bitumen becomes liquid and rises to the surface, and the stone falls to the bottom in grains of sand. The bitumen is then skimmed off. If, however, the sand be in very fine grains, a considerable quantity of it becomes mixed in the boiling with the bitumen, and rises with it to the surface of the water. A second operation, therefore, becomes necessary in order to render the bitumen sufficiently free from sand. For this purpose it is placed in another caldron, and heated to such a degree as to render it quite liquid. The water remaining in the skimmings soon evaporates, and the sand falling to the bottom, the pure bitumen is drawn off. In this second operation a considerable quantity of bitumen is lost in consequence of the impracticability of separating it from the sand at the bottom of the caldron. Of late years bitumen is sometimes extracted by chemical solution, and the liquid in which it has been dissolved drawn off by evaporation. A small admixture of pure sand is of very little detriment for most purposes to which bitumen is applied; but it is essential that it should be free from earthy or vegetable matter. In extracting bitumen from such soils as that in which it is found in the island of Trinidad, it is necessary to resort to complex chemical processes, and even then the result is inferior to the products of the bituminous sandstones.

Bitumen has been used from remote antiquity, and probably asphalte also may have been known to the ancients; but it does not appear to have been applied to its present uses until the beginning of the eighteenth century. The first mine of asphalte was that of the Val-de-Travers, near Neuchâtel, in Switzerland. It was discovered by Dr. d'Eyrinis, who published in the year 1721 a small volume, in which the nature and uses of asphalte are very fully explained, and its adoption for various purposes enthusiastically advocated. It was not, however, until 1838 that the first pavements of asphalte were laid in the streets of Paris.

The valuable properties of asphalte now became fully appreciated; and not only so, but they were greatly exaggerated, and the material applied to purposes for which it was not adapted. About this time asphalte produced an industrial fever not unlike the celebrated South-Sea Bubble or the more recent railway mania. Societies were formed in Paris, whose shares increased in price within a few months to ten times their original cost; and then in a very short time a reaction occurred, and one-tenth of the original cost could not be obtained for the same shares. The evils of excessive speculation disappeared in course of time, and at present the production and application of asphalte is an extensive and well-regulated branch of industry. It is much more used on

the continent of Europe than in England. It is the material generally adopted for the pavements of Paris, and indeed for very many of the carriage-roads. During the period of excitement several companies were formed in England for the supply and application of asphalte, and amongst others, one promoted by Claridge, and one known as the Metropolitan Mineral Rock and Asphalte Company, which still maintain the highest character for excellence of materials and workmanship.

The best description of asphalte consists of a limestone composed of nearly pure carbonate of lime, impregnated with from six to ten parts by weight of bitumen. The principal source of supply at the present time is from the Jura Mountains, in the neighbourhood of Seyssel, on the west bank of the river Rhone.

The colour is a dark chocolate, approaching to black. In cold weather the stone is hard, and easily broken; but in warm weather it softens under the blow of the hammer. The specific gravity is about 2·25.

The bituminous limestone, after being quarried, is broken to a size that would pass through a ring about 2½ inches in diameter. It is then reduced to powder, either by grinding, or by crushing, or by exposure to heated steam. The first method is generally preferred; but when the stone is hard and deficient in bitumen, it is more convenient to crush it between revolving cylinders; on the other hand, with stone which is soft and contains an excess of bitumen, the hot vapour process may be more advantageous, especially in warm weather. The powder requires to be sifted, and all the large particles again passed through the mill, or otherwise reduced to the requisite degree of fineness. The next process is to place the powder in a caldron, in which a small quantity of pure bitumen has been previously melted, and to bring it into a state of fusion and stir it by machinery until the whole is thoroughly mixed, when it is drawn off and run into moulds to form blocks of about 1 cwt. These blocks, when cold, are ready for exportation as asphaltic mastic. The finest mastic contains 87 per cent. of the carbonate of lime and 13 per cent. of bitumen, but several qualities of mastic are prepared by adding to the other ingredients various proportions of very coarse-grained sand, termed "grit." The mastic requires to be remelted on the spot, where it is to be used in the laying of pavements or other works; and for this purpose portable caldrons are provided, and a small quantity of the mineral tar is added, as a flux, with every melting.

Mastic of pure asphalte is seldom used without some admixture of grit, a certain proportion of which adds to its power of enduring wear and tear, and of resisting the tendency to soften at high temperatures. Asphalte containing about 15 per cent. of fine grit is best adapted for covering roofs, and that containing about 25 per cent. of coarse grit for the laying of footpaths. Asphalte pavements should not become appreciably soft when subjected to a temperature of 160° Fahrenheit.

The principal uses of asphalte are for covering roofs; for protecting underground vaults, magazines, railway-arches, &c., from the percolation of water; for pavements; and for damp-courses, to prevent moisture from rising in walls by capillary attraction. A layer of asphalte ⅜-inch in thickness may be considered impervious to moisture, and, therefore, an effectual damp-course. As a covering to roofs, it is exposed to variations of temperature, which are destructive to cement and most other compositions, and frequently cause cracks even in lead; but good asphalte, ¾-inch in thickness, firmly supported on a thick bed of concrete, will form a substantial water-tight covering through all alternations of climate. As a pavement it has the advantage of being free from joints, of presenting a very smooth surface, and of being capable of enduring a great amount of wear. A good paving of asphalte, ¾-inch thick, will last longer under heavy traffic than Yorkshire flagging 3 in. thick. As a covering for underground arches it may not be considered very much superior to Portland cement, but it has the advantage of possessing a certain degree of elasticity, which renders it less liable to crack upon slight settlements occurring in the brickwork or masonry underneath it. One great recommendation for asphalte is, that it is easily repaired; and that the materials from old work may be melted and, with a small addition of mineral tar, re-used in new work.

The dark colour of asphalte pavements is somewhat to its disadvantage; and the closeness of its texture, and its property of readily condensing on its surface the moisture of a damp atmosphere, renders it unsuitable for the floors of inhabited apartments. Its property of becoming soft at a high temperature renders it unfit for floors of furnace-rooms, forges, &c., or for any close proximity to fires. On the other hand, it is to be observed that, though liable to melt, it never takes fire, and that it is, therefore, well adapted for fire-proof construction.

Asphalte has been used as a cement in the brickwork of tanks, &c.; but for such purposes it appears to possess very little, if any, advantage over Portland cement, which is a much cheaper material. It has very little adhesion for brick or stone; and, consequently, however superior the asphalte itself may be in regard to strength and impermeability, it does not, in combination, form a solid homogeneous mass of masonry. The absence of adhesion also prevents it from being applicable as a covering or lining to vertical surfaces.

Good asphalte is not much affected by the ordinary variations of temperature; but still it becomes somewhat soft under a summer sun, and is liable to slide down if laid upon a steep incline. Asphalte roofs and pavements should, therefore, be laid nearly horizontal, and when steep inclines are unavoidable, they should not be more than about two or three feet in width. Vertical surfaces above 6 inches in height should be avoided when practicable; but, with care, greater heights may be executed with safety, especially in short lengths.

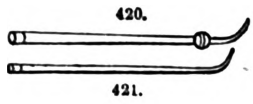
The preparation of asphaltic mastic and mineral tar, as above described, is evidently somewhat expensive; and the carriage of the material adds greatly to the cost, especially in this country, which has no source of supply nearer than the Jura Mountains. The bitumen is known to be very similar to some cheaper substances, and, among others, to common coal-tar; and carbonate of lime of similar quality to that of the bituminous limestone is easily obtainable in almost every locality. There is, therefore, every inducement to endeavour to produce an artificial compound, which may supply the place of natural asphalte. The effort to invent such a compound merits approbation, and has been successfully made by the Metropolitan Asphalte Company. Up to the present time, every artificial asphalte has proved to be a failure in cases where strength was required, or where

exposed to great alternations of temperature. Preparations of coal-tar have been advantageously employed in protecting walls, arches, &c., from damp, when the artificial asphalte could be itself protected from the weather and the air excluded; and tar pavements are extremely cheap, and well adapted for many situations.

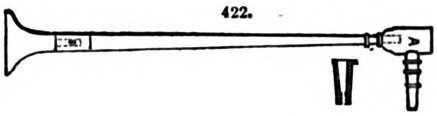
ASSAYING. Fr., *Essai des Métaux*; Ger., *Probirkunst*; Ital., *Saggio dei Metalli*; Span., *Ensayo de metales*.

The term "assaying" is frequently used in the general sense of chemical analysis; but, strictly, it is only applicable to that mode of separating metals from their ores, or *gold* and *silver* from the baser metals, in which no wet reagents, generally speaking, are employed, and the action of heat is called into play. We shall, in this article, give concise methods for enabling any one to detect in commercially valuable minerals and ores those constituents of which they are composed.

The forms of *blowpipe* generally used for assaying are shown in Figs. 420, 421. They consist of a tube made of *brass* or of *german-silver*, bent near the end, and terminated with a finely-pointed nozzle. The best form of blowpipe is represented in Fig. 422. The tube and nozzle are made of


420.

421.


422.

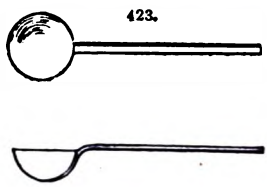
the same material as the common blowpipe, the point of platinum, and the mouthpiece of horn, wood, or ivory. The air-chamber A serves to partially regulate the blast, and receives the tube and nozzle, which are ground to fit accurately, each of these pieces being movable. The point, which enters the flame, as before observed, is made of platinum.

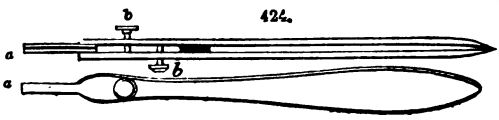
In using the blowpipe, the lips are pressed against the mouthpiece, and the stem firmly held; the cheeks are inflated with air, which is expelled from the mouth through the pipe, by contracting the muscles of the cheeks, care being taken to inhale only through the nostrils; by this means a continuous flame is kept up.

When a flame is propelled by a current of air blown into or upon it, the flame produced may be divided into two parts, possessing respectively the properties of reduction and oxidation. The reducing-flame is produced by a weak current of air acting upon the flame of a lamp or candle; the carbon contained in the flame is thus brought in contact with the substance to be examined, which it reduces. The oxidizing-flame is formed by blowing strongly into the interior of the candle-flame. Combustion is thus thoroughly effected; and if a small piece of an oxidizable body be held at the point of the flame, the former speedily acquires an intense heat, and combines freely with the oxygen of the surrounding air. The substance to be analyzed should, when exposed to the flame of the blowpipe, be supported upon some infusible, and, in many cases, incombustible material.

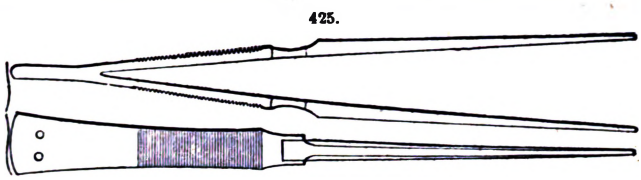
When it is required to reduce an oxidized substance, to fuse a body without oxidizing it, or to oxidize a body on which the reducing action of carbon alone is unimportant, that body is placed in a small hollow in a piece of charcoal. The best kind of charcoal for this purpose is made from closely-grained pine-wood, free from knots, and should be cut by a small, fine saw into convenient pieces.

For holding in the flame substances which would be affected by charcoal, platinum-wire, 0·012 in. diameter, is formed into a small hook. The hook is heated and dipped into borax or microcosmic salt, which adheres to it, forming a small globule in which the substance to be tested is placed. Platinum-foil is used for the same purposes as the wire. Platinum spoons, shaped as in Fig. 423, are used for fusing the mineral with reagents, as carbonates of potash and soda,


423.




bisulphate of potash, and saltpetre. When the substance can be determined by the colour it gives to the blowpipe-flame, it is held in the latter by brass or steel forceps with platinum tips, Figs. 424, 425. To take up the mineral, the knobs *b b*, Fig. 424, are pressed, the platinum points *a, a*


425.

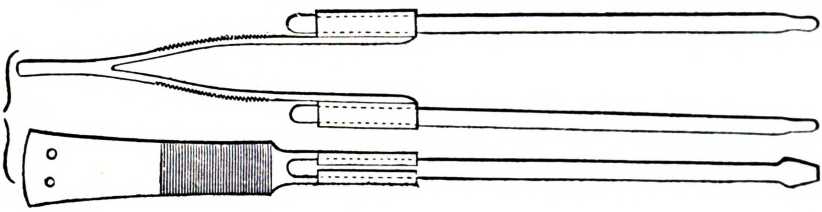
then open, and close, when required, by their own elasticity. For manipulating in acids, forceps with glass points, Fig. 426, are used.

Glass tubes of various diameters, in lengths of 5 or 6 in., open at both ends, are used for roasting substances containing *sulphur*, selenium, *arsenic*, *antimony*, and tellurium. These, when heated with an access of air, evolve characteristic fumes. They are generally heated by a spirit-

lamp. Small test-tubes are also required, in order to detect the presence of water, mercury, or other bodies which are volatilized by heat without access of air.

The reagents most commonly used in assaying are carbonate of soda, borax, and microcosmic salt. The carbonate of soda must be anhydrous and perfectly pure. It is chiefly used to reduce metallic oxides and sulphides, to decompose silicates, and to determine the fusibility of different substances.

426.



Pure borax is heated below its melting-point to expel its water of crystallization, and is then pulverized. In using borax, a small quantity is formed into a bead on the end of a platinum-wire, to this bead is then added a minute quantity of the powdered substance to be examined. The whole is then held in the blowpipe-flame, and the following results observed:—whether the borax dissolve the substance or not; the colour of the bead formed in the oxidizing and reducing flames respectively; and whether the colour of the bead alter when cooling. Only sufficient of the substance should be added to give a colour to the bead; if this be too intense to be clearly distinguished, more borax may be added. When microcosmic salt, which is a combination of phosphate of soda and ammonia, is used, it should be fused upon platinum-foil, to expel the water and excess of ammonia contained in it. It is then used upon platinum-wire in the same way as borax.

The following reagents are required in certain cases:—nitrate of potash, also called saltpetre, for oxidizing certain substances by fusing with them either on platinum-foil or in the platinum spoon; bisulphate of potash, for eliminating certain volatile matters, as lithia, boracic acid, hydrofluoric acid, bromine, iodine, also for decomposing salts of titanic, tantalic, or tungstic acids; nitrate of cobalt, chemically pure and in solution, for detecting the presence of alumina, magnesia, oxide of zinc, oxide of tin, and titanic acid, which, when moistened with this reagent and strongly heated, assume certain characteristic colours; silica, for various purposes; fluoride of calcium, known as fluor-spar, which, mixed with bisulphate of potash, is used for ascertaining the presence of lithia and boracic acid; oxide of nickel or oxalate of nickel, which latter is a salt of oxide of nickel with oxalic acid, for the detection of potash in large quantity in salts which also contain soda and lithia; protoxide, black oxide, of copper, for detecting chlorine, bromine, and iodine; tin-foil, for reducing various metallic oxides dissolved in borax or microcosmic salt (the hot fluid is touched on charcoal with a piece of tin-foil, and then strongly heated for some seconds under the reducing-flame); fine silver, for discovering sulphur and sulphuric acid. The reagents should be kept in glass-stoppered bottles.

In addition to the apparatus already described, the following articles are desirable, though, with some exceptions, not indispensable; a steel hammer, a small anvil, a steel crushing-mortar, an agate mortar, two or three files, a pair of scissors, a magnet, a pocket-lens, some porcelain capsules, a spirit-lamp, and a good pocket-knife; blue litmus-paper, turmeric-paper, small quantities of strong sulphuric, nitric, and hydrochloric acids, and a few glass rods.

Methods of Analysis.—*In the Test-tube.*—The tube being thoroughly dry and clean, a small portion of the pulverized substance under examination is placed in it, and heated over a spirit-lamp until the glass softens; it must then be noticed whether any vapour or sublimate is collected in the upper portion of the tube. This vapour may be water, mercury, sulphur, selenium, tellurium, or arsenic. If the product be liquid, its alkaline or acid reaction should be tested by litmus-paper. Organic substances may be detected by their odour. Quicksilver can be discovered in the sublimate by means of a lens. The sublimate of selenium is reddish brown, of tellurium grey, and of arsenic black; that of the latter being sometimes metallic. If these substances do not appear as sublimates, it must not be concluded that they are not present, as they may exist in combinations not readily destroyed by heat alone. Oxygen and ammonia are sometimes evolved; the former may be recognized by introducing an incandescent splinter of wood, which will immediately burst into a flame; and the latter by its alkaline reaction upon moistened red litmus-paper. Often, however, ammonia exists in such a state of combination, that heat alone will not disengage it. When any substance is supposed to contain such a combination, it must be mixed with caustic soda, or caustic lime, and heated in a clean test-tube, when free ammonia will escape.

*In the Open Tube.*—The substance in a state of powder is placed in the tube half an inch from one end, and heated by degrees, the tube being slightly inclined in order to produce a current of air. The constituents of the substance thus combine with the oxygen of the air, and are volatilized. Sulphur forms sulphurous acid, which is detected by its pungent smell. Selenium forms a steel-grey deposit, and also a vapour, characterized by its smell. Arsenic volatilizes as arsenious acid, antimony as antimonious acid, and tellurium as tellurous acid, all forming dense white fumes. The deposit from arsenic is crystalline, from the others amorphous; that from tellurous acid forms small beads. The tubes used should be made of difficultly fusible German or Bohemian glass.

*On Charcoal.*—The action of most substances when heated on charcoal is similar to their action in the test-tube. The experimenter should make himself familiar with the incrustations formed by different substances when heated on charcoal. We will only describe the action of those substances which are of practical importance.

REACTIONS OF SOME OF THE MORE COMMON METALLIC OXIDES, WITH BORAX AND WITH MICROCOSMIC SALT, ON PLATINUM-WIRE, IN BOTH FLAMES.

| METALLIC OXIDES. | WITH BORAX. | | WITH MICROCOSMIC SALT. | |
|---|---|---|---|---|
| | OXIDIZING-FLAME. | REDUCING-FLAME. | OXIDIZING-FLAME. | REDUCING-FLAME. |
| Oxide of Manganese, $Mn_2 O_3$. | Affords an intense amethyst colour, which on cooling becomes violet. A large quantity of the oxide produces an apparently black bead, which, however, if pressed flat, is seen to be transparent. | The coloured bead becomes colourless. With a large amount of the oxide, this reaction is best obtained upon charcoal, and is facilitated by the addition of tin-foil. | With a considerable quantity of oxide, an amethyst colour is obtained, but never so dark as in borax. A small quantity of oxide only having been taken, a colourless bead is obtained, in which, however, the amethyst colour may be brought out by the addition of a little nitre. While the bead is kept fused, it froths and gives off bubbles of gas. | The coloured bead immediately loses its colour, either on platinum-wire or on charcoal. After the reduction the fluid bead remains still. |
| Oxide of Iron, $Fe_2 O_3$. | With a small proportion of oxide, the bead is of a yellow colour while warm, and colourless when cold; with a larger proportion, red while warm, and yellow when cold; and with a still larger amount, dark red while warm, and dark yellow when cold. | Treated alone on platinum-wire, the bead becomes of a bottle-green colour, and if touched with tin, it becomes a pale sea-green. On charcoal with tin, it assumes at first a bottle-green colour, which by continued blowing changes to a sea-green. | With a certain amount of oxide, the bead is of a yellowish-red colour, which on cooling changes to yellow, then green, and finally becomes colourless. With a large addition of oxide, the colour is, when warm, dark red, and passes, while cooling, into brownish-red, dark green, and finally brownish-red. During cooling, the colours change more rapidly than is the case with borax. | With a small proportion of oxide there is no reaction. With a larger amount, the bead is red, while warm, and becomes, on cooling, successively yellow, green, and russet. With the addition of tin the bead becomes, during cooling, first green, and then colourless. |
| Oxide of Cobalt, Co O. | Colours the bead of an intense blue, both whilst hot and when cold. When much oxide is present, the colour is so deep as to appear black. | As in the oxidizing-flame. | As with borax, but less intensely coloured. During cooling the colour becomes somewhat paler. | As in the oxidizing-flame. |
| Oxide of Nickel, Ni O. | Colours intensely. A small amount of oxide affords a bead which, while warm, is violet; and becomes of a pale reddish-brown on cooling. A larger addition produces a dark violet colour in the warm, and reddish-brown in the cold bead. | The oxide is reduced, and the metallic particles give the bead a turbid grey appearance. If the blast be continued, the metallic particles fall together without fusing, and the bead becomes colourless. This reaction is readily obtained with tin upon charcoal, and the reduced nickel fuses to a bead with the tin. | Dissolves into a reddish bead, which becomes yellow on cooling. With a large addition of the oxide, the bead is brownish while hot, and orange when cold. | On platinum-wire the nickeliferous bead undergoes no change. Treated with tin upon charcoal, it becomes at first opaque and grey; and, after long-continued blowing, the reduced nickel forms a bead, which remains colourless. |

| | | | | |
|---|---|---|---|---|
| Oxide of Zinc, Zn O. | Dissolves easily into a clear, colourless bead, which, when much oxide is present, may be rendered opaque and flocculent by an intermittent flame, and become so spontaneously with a still larger addition of the oxide. When a considerable quantity is dissolved, a bead is obtained, which is pale yellow while hot, and colourless when cold. | On platinum-wire the saturated bead becomes at first opaque and grey, but by a sustained blast is again rendered clear. On charcoal the oxide is gradually reduced; the metal is volatilized, and encrusts the charcoal with oxide. | As with borax. | As with borax. |
| Oxide of Lead, Pb O. | Dissolves readily to a clear yellow bead, which loses its colour upon cooling, and, when containing much oxide, can be rendered dull under an intermittent flame. With a still larger addition of oxide, it becomes opaque yellow on cooling. | The plumbiferous bead spreads out on charcoal, becomes turbid, bubbles up, until the whole of the oxide is reduced, when it again becomes clear. It is, however, difficult to bring the lead together into a bead. | As with borax; but a larger addition of oxide is required to produce a yellow colour in the warm bead. | On charcoal the plumbiferous bead becomes grey and dull. With an excess of oxide, a part is volatilized, and forms an incrustation on the charcoal beyond the bead. The addition of tin does not render the bead opaque, but somewhat more dull and grey than in its absence. |
| Oxide of Tin, $Sn O_2$. | In small quantity dissolves slowly into a clear, colourless bead, which, when cold, remains clear, and cannot be rendered opaque with an intermittent flame. If a saturated bead, which has been allowed to cool, be reheated to incipient red heat, it loses its rounded form, and exhibits imperfect crystallization. | A bead containing but little oxide undergoes no change. If much of the latter be present, a part may be reduced upon charcoal. | In small quantity dissolves very slowly to a colourless bead, which remains clear on cooling. | The bead undergoes no change, either on charcoal or platinum-wire. |
| Oxide of Bismuth, $Bi O_3$. | Dissolves readily to a clear bead, which, with a small amount of the oxide, is yellow while warm, and becomes colourless on cooling. With a large addition, the bead is, in the hot state, of a deep orange colour, which changes to yellow, and finally becomes opaline, in process of cooling. | The bead becomes at first grey and turbid, then begins to effervesce, which action continues during the reduction of the oxide, and it finally becomes perfectly clear. If tin be added, the bead becomes at first grey, from reduced bismuth, but, when the metal is collected into a bead, the bead is again clear and colourless. | Dissolves in small quantity to a clear, colourless bead. A large addition of oxide affords a bead which, while warm, is yellow, and becomes colourless on cooling. When in sufficient proportion, the bead may be rendered opaque, and, under an intermittent flame, a still larger addition of oxide renders the bead spontaneously opaque on cooling. | On charcoal, and especially with the addition of tin, the bead remains colourless and clear while warm, but becomes, on cooling, of a dark grey colour, and opaque. |

REACTIONS OF SOME OF THE MORE COMMON METALLIC OXIDES, WITH BORAX AND WITH MICROCOSMIC SALT, ON PLATINUM-WIRE, IN BOTH FLAMES—*continued.*

| METALLIC OXIDES. | WITH BORAX. | | WITH MICROCOSMIC SALT. | |
|---|---|---|---|---|
| | OXIDIZING-FLAME. | REDUCING-FLAME. | OXIDIZING-FLAME. | REDUCING-FLAME. |
| Oxide of Copper, Cu O. | Produces an intense colouration. If in small quantity, the bead is green, while warm, and becomes blue on cooling. If in large proportion, the green colour is so intense as to appear black. When cool, this becomes paler, and changes to a greenish-blue. | If not too saturated, the cupriferous bead soon becomes nearly colourless, but immediately on solidifying assumes a red colour, and becomes opaque. By long-continued blowing on charcoal the copper in the bead is reduced, and separates as a small metallic bead, leaving the remainder colourless. With the addition of tin, the bead becomes of an opaque, dull red, on cooling. | With an equal proportion of oxide as applied to borax this salt is not so strongly coloured. A small amount imparts a green colour in the warm, and a blue in the cold. With a very large addition of oxide, the bead is opaque in the hot state, and, after cooling, of a greenish-blue. | A tolerably saturated bead assumes a dark green colour under a good flame, and, on cooling, becomes of an opaque brick-red, the moment it solidifies. A bead containing but a small proportion of the oxide becomes equally red and opaque on cooling, if treated with tin upon charcoal. |
| Oxide of Mercury, Hg O. | No reaction. | No reaction. | No reaction. | No reaction. |
| Oxide of Silver, Ag O. | The oxide is partly dissolved, and partly reduced. In small quantity it colours the bead yellow while warm, the colour disappearing on cooling. In large quantity the bead is yellow while warm, but during cooling becomes paler to a certain point, and then again deeper. If re-heated slightly, the bead becomes opalescent. | On charcoal the argentiferous bead becomes at first grey, from reduced metal, but afterwards, when the silver is collected into a bead, it becomes clear and colourless. | Both the oxide and metal afford a yellowish bead, which, when containing much oxide, becomes opaline, exhibiting a yellow colour by daylight, and a red one by artificial light. | As with borax. |
| Oxide of Antimony, $Sb_2O_3$. | Even when in large proportion dissolves to a clear bead, which is yellow while hot, but almost entirely loses its colour on cooling. On charcoal the antimonious acid may be almost expelled, so that tin produces no further change. | A bead that has only been treated for a short time in the oxidizing-flame, when submitted to the reducing-flame becomes grey and turbid, from the reduced antimony. This soon volatilizes, and the bead again becomes clear. The addition of tin renders the bead ash-grey, or black, according to the amount of oxide it contains. | Dissolves, with ebullition, to a bead of a pale yellow colour while warm. | On charcoal the saturated bead becomes at first dull, but as soon as the reduced antimony is volatilized it again becomes clear. With tin the bead is at first rendered grey by the reduced antimony, but by continued blowing is restored to clearness. Even when the bead contains but little oxide, tin produces this reaction. |

*Arsenic*, when heated upon charcoal by the blowpipe-flame, covers the former with a coating, white in the centre and grey at the edges, of arsenious acid. This coating is immediately volatilized, when brought in contact with the flame, and gives off the odour of garlic which characterizes arsenic. The vapour evolved is highly poisonous, and should not be inhaled. Metallic arsenic dissolves readily in nitric and hydrochloric acids; in the first case, if heat be applied and an excess of acid used, arsenic acid will be formed; and in the second, arseniuretted hydrogen, a very poisonous gas, is evolved, leaving chloride of arsenic.

*Antimony* melts easily, coating the charcoal under both the oxidizing and reducing flames, with an incrustation—white where thick, and bluish where thin—of antimonious acid. Antimonious acid is less volatile than arsenious acid, and tinges the reducing-flame blue; but is simply melted by the oxidizing-flame. Antimonious acid, when moistened with a solution of nitrate of cobalt, and gradually brought to a high temperature in the oxidizing-flame, after cooling, presents a dusky green appearance. The best solvent for antimony is aqua regia, nitro-muriatic acid, which converts it into chloride of antimony.

*Bismuth* melts readily, and coats the charcoal, under both flames, with its oxide. The colour of this coating resembles that of an orange, and becomes paler on cooling. The edges of the oxide, which have been more exposed to the action of the charcoal, become converted into carbonate of bismuth, which is white. By applying either flame the oxide is driven from place to place, being first reduced by the charcoal to metallic bismuth, which is volatilized and re-oxidized. The colour of the flame undergoes no alteration. Bismuth dissolves in nitric acid, from its solution in which it may be precipitated as a white sediment by dilution with pure water.

*Copper*.—This metal, when unalloyed, melts easily before the blowpipe. When placed in the oxidizing-flame it becomes coated with black oxide of copper, while the flame is strongly tinged with green. Metallic copper is easily obtained from its oxide in the reducing-flame, without incrusting the charcoal. Many compounds of copper may be reduced to the metallic state by mixing them with carbonate of soda, and then heating in the reducing-flame. Copper dissolves readily in nitric acid, giving off nitrous fumes, and forming a deep azure-blue solution on the addition of ammonia. A polished surface of iron or steel, immersed in a solution of copper, soon becomes coated with this metal.

*Gold* melts easily before the blowpipe, is not acted on by fluxes, and is soluble in aqua regia.

*Lead* fuses readily, covering the charcoal with oxide of a dark yellow colour, which becomes paler on cooling. Beyond the oxide, carbonate of lead is formed, of a bluish-white colour. The oxide, when heated in the oxidizing-flame, acts in the same manner as the oxide of bismuth; but in the reducing-flame it volatilizes, tinging the flame blue. Lead readily dissolves in nitric acid; and its oxide, litharge, is soluble even in vinegar.

*Platinum*.—Infusible, not affected by borax or microcosmic salt, except in a state of fine dust, when reactions for iron or copper, which occur in small quantities, as impurities, take place. It is soluble only in boiling aqua regia.

*Silver*, when fused alone upon charcoal, covers it with a thin coating of dark brown oxide. If lead be present, it first forms a yellow oxide; then, as the silver becomes purer, the silver forms a dark red deposit beyond. Antimony, when present, forms a white crust of antimonious acid, which, on further exposure to the heat, becomes red on the exterior. If antimony and lead are simultaneously present in the silver, a crimson incrustation forms upon the charcoal after the former metals have been volatilized. Rich silver ores sometimes produce the same result, when fused upon charcoal. Silver dissolves readily in nitric acid, and may be re-deposited by a plate of copper.

*Tin* melts readily, and oxidizes in the inner flame. The melted metal, when exposed to the reducing-flame, becomes covered, as well as the charcoal, with oxide, which is pale yellow while hot, and becomes white when cool. This oxide cannot be reduced by either flame. The best solvent for tin is hydrochloric acid; nitric acid oxidizes this metal, but has no effect upon its oxide.

*Zinc* melts with facility, and burns with a bright greenish-white flame in the oxidizing-flame. The product of this combustion is oxide of zinc, evolved in dense white fumes, which coat the charcoal. This coating, while hot, is yellow, and turns white on cooling; it shines brilliantly when heated with the oxidizing-flame, but cannot be volatilized. The reducing-flame volatilizes it but slowly. Zinc is readily soluble in dilute sulphuric acid, hydrogen being evolved, and sulphate of zinc formed.

*In Platinum Forceps*.—If the substance to be examined does not attack platinum, a small fragment held in the forceps is exposed to the oxidizing-flame; if its action upon platinum is feared, it should be placed upon charcoal or refractory porcelain. In this method of examination the substance is recognized by the colour it imparts to the flame. The following are a few substances of frequent occurrence classified according to the colours which they give to the blowpipe-flame:—

| Blue Flame. | Green Flame. | Red Flame. | Violet Flame. |
|---|---|---|---|
| Arsenic .. light. | Copper .. emerald. | Lime .. purplish. | Potash .. clear. |
| Antimony .. greenish. | Baryta .. pale. | Lithia .. crimson. | |
| Bromide of copper } mixed with green. | Boracic acid dark. | Strontia .. dark crimson. | |
| Chloride of copper } intense. | Ammonia .. very dark. | | |
| Lead .. .. pale, clear. | Iron .. .. dark. | | |
| Selenium .. azure. | Iodide of copper } intense emerald. | | |
| | Phosphoric acid } pale. | | |
| | Zinc .. .. very pale. | | |

*With Borax.*—As this method serves to distinguish metallic oxides, all substances containing unoxidized metals must be previously roasted, in order to convert them into oxides. The same treatment is necessary when microcosmic salt is substituted for borax.

*With Carbonate of Soda.*—The substance to be analyzed is powdered and made into a paste with carbonate of soda and water. A small portion of the paste is then gradually heated upon the charcoal until the temperature is as high as possible. Three reactions may then take place: either the substance will fuse with effervescence, it will be reduced, or the alkali will be absorbed into the charcoal, leaving the substance on the surface unchanged. Silica, titanic and tungstic acids fuse with effervescence.

The oxides of gold, silver, tungsten, antimony, arsenic, copper, mercury, bismuth, tin, lead, zinc, iron, nickel, and cobalt, when mixed with carbonate of soda and heated upon the charcoal in the reducing-flame, are reduced. Lead, zinc, antimony, and bismuth, volatilize partially, forming incrustations on the charcoal. Mercury and arsenic are volatilized as soon as reduced, leaving no marks upon the charcoal.

That part of the charcoal upon which the assay has rested must be pulverized in a mortar, when any metal which may be contained in it will be found in the form of a shining metallic powder, if brittle, or flakes, if malleable.

Sulphur may be detected by heating the substance with double its weight of carbonate of soda, upon charcoal, in the reducing-flame. The assay and that portion of the charcoal which has absorbed any alkali are powdered and placed upon a moistened surface of polished silver, which, if sulphur be present, receives a black stain.

Manganese is detected by fusing the substance with carbonate of soda and nitre, upon platinum, in the oxidizing-flame. The bead thus formed is of a turquoise colour when cool.

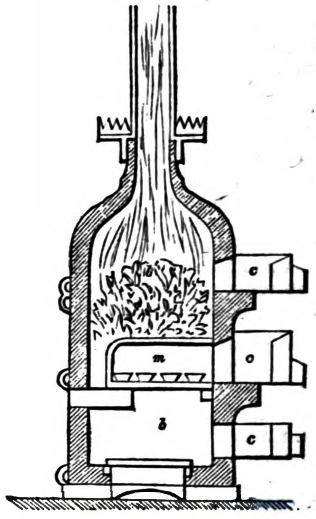
In order to detect quantities of phosphorus too minute to give any reaction in the blowpipe-flame, part of the substance is pulverized with five times its bulk of a mixture of 3 parts carbonate of soda, 1 nitrate of potash, and 1 silica, and the whole fused in a platinum spoon or crucible. The resulting mass is mixed with water, filtered, and a few drops of carbonate of ammonia added; the silica is precipitated by boiling, and removed by filtration. A small quantity of acetic acid is then added to the filtrate, which is boiled to expel the carbonic acid, and to which pure nitrate of silver is added. If phosphorus or phosphoric acid be present, a yellow precipitate appears; if, on the contrary, the solution contain arsenic, or any compound of that metal, the precipitate is of a reddish-brown colour.

*Assay of Fuel.*—To estimate approximately the amount of carbon in any particular fuel, a portion of the fuel should be dried, weighed, and heated in a platinum crucible until further increase of temperature causes no reduction in weight. The difference between the weight of the remaining ashes and that of the substance previous to heating gives the desired result.

*Assay of Gold and Silver.*—In assaying gold, the metal is wrapped, with three times its weight of fine silver and twelve times its weight of pure lead, in a piece of thin paper, and melted in a bone-ash *cupel*, Fig. 427. This cupel is either heated in a muffle, shown at *m*, Fig. 428, or by the oxidizing-flame of a blowpipe. The lead and copper become oxidized, the fused oxide of lead dissolves that of the copper, and both are absorbed by the cupel, leaving the gold and silver combined in the form of a button. This button should be rolled into a thin plate and boiled with nitric acid, spec. grav. 1·18, which extracts the greater part of the silver. The remainder is then washed with pure water, and boiled in nitric acid, spec. grav. 1·28, to extract the last traces of silver; after which it is washed, heated to redness in a crucible, and weighed.

427.

428.




*m*, muffle. *b b*, fire.
*c c c*, furnace-doors.

The assay of silver is generally conducted by the wet process, and is based on the fact that chloride of silver is an insoluble salt, and that a solution of common salt can be made of such a strength as to precipitate a certain weight of pure silver from a solution of that metal in nitric acid.

Lead may be extracted from galena, its sulphide, and its most common ore, by mixing 300 grains of galena with 450 grains of dried carbonate of soda and 20 grains of charcoal, and placing it in a crucible with two large iron nails, heads downwards. This crucible is covered, and heated moderately for half-an-hour. The remainder of the nails is carefully removed from the liquid mass, which is then allowed to cool, the crucible broken, and the lead extracted and weighed.

To ascertain if it contains silver, the button is placed in a small bone-ash cupel, heated in a muffle, until the whole of the lead is oxidized and absorbed by the bone-ash the cupel is made of, leaving the minute globule of silver. Small globules of lead may be conveniently cupelled on charcoal before the blowpipe, by pressing some bone-ash into a cavity scooped in the charcoal, placing the lead upon its surface, and exposing it to a good oxidizing-flame as long as it decreases in size. If any copper be present, the bone-ash will show a green stain after cooling. Pure lead gives a yellow stain. In the above process the sulphur of the lead ore, galena, is removed partly by the sodium of the carbonate of soda, and partly by the iron of the nails, the excess of carbonate of soda serving to flux any silica with which the galena may be mixed. (See Articles on the various Metals.)

*Works relating to Assaying*:—Berthier, 'Traité des Essais par la voie séche,' 2 vols., 8vo, Paris, 1848. 'Records of Mining and Metallurgy,' by J. Arthur Phillips and John Darlington, crown 8vo, 1857. Scheerer and Blandford, 'An Introduction to the Use of the Mouth Blow-pipe,' 12mo, 1864. J. Silversmith's 'Handbook for Miners, Metallurgists, and Assayers,' 12mo, New York, 1866. G. Kurstel, 'Nevada and California Processes of Gold and Silver Extraction,' 8vo, San Francisco, 1866. B. Kerl, 'Metallurgische Probirkunst,' royal 8vo, Leipzig, 1866. J. Arthur Phillips, 'Mining and Metallurgy of Gold and Silver,' royal 8vo, 1867. Mitchell's 'Manual of Practical Assaying,' 3rd edition, 8vo, 1868.

ATOM. Fr., *Atome*; Ger., *Atom*; Ital., *Atomo*; Span., *Atomo*.

Bodies are not composed of one continuous substance, but—as is evidenced by their porosity and their faculty of increasing or diminishing their volume under certain influences, and even of changing their actual state—they are formed of an aggregation of small particles, called *molecules*, placed at specific distances from each other, and maintained in equilibrium by the powers of attraction and repulsion which they reciprocally exercise.

These molecules, however, are not the final limit of subdivision of which matter is susceptible. By bringing other forces into play, it is possible, in most cases, to divide them into yet smaller masses.

It is to these last that the name of *atom* has been given.

We have said "*in most cases*," because there are some exceptional ones when the molecule is *not* divisible.

The bodies to which they appertain are then said to have an atom and a molecule that are homologous.

By knowing the atomic weights of all the simple bodies, and the molecular weights of either the elements or the compounds which they form, we arrive at far more correct notions regarding the constitution of bodies, than by trusting solely to the rough fact of equivalents. See Molecule.

How the first of these are attainable will be shown in the next article.

ATOMIC WEIGHTS. Fr., *Poids atomiques*; Ger., *Atomgewicht*; Ital., *Pesi atomichi*; Span., *Pesos atomicos*.

Higgins and Dalton were the first to think of explaining chemical combinations by the hypothetical juxtaposition of atoms. Dalton argued that, those atoms being insecable, the various quantities of a body A, which unite with an invariable quantity of another body B, must bear to each other ratios that are rational and commensurable. From this atomical hypothesis he then deduced, *a priori*, the law of multiple proportions, which, after receiving the sanction of experience, has become one of its most solid foundations.

The atomical theory affords a satisfactory explanation of equivalents, that is to say, of the fact that bodies enter into combinations in quantities bearing the same ratio, though they vary between themselves.

For example, let us suppose the weight of one atom of potassium to be 39 times greater than that of one atom of hydrogen, and that one atom of the one or the other of those bodies to one atom of chlorine is required in order to form a definite combination. As the weight of the atom of chlorine remains the same in both cases, it is evident that, to saturate it, it will take 39 times the weight of potassium that would be required of hydrogen. Moreover, as these proportions cannot alter, although, instead of two atoms, an indefinite number enter into combination, the result is, in general, that to saturate any given quantity of chlorine, it will take 39 times more potassium than hydrogen. This is what is meant when we say that the relative equivalent of potassium to that of hydrogen, taken as unity, is 39. In the atomical theory, the equivalents of bodies thus become the weight of their atom compared to the weight of an atom of hydrogen taken as unity, and are known under the name of *Atomic Weights*.

The notion of atomic weight carries with it, however, something more precise than that of equivalent. It is another ratio, but one more fully determined.

For instance, let us suppose an atom of oxygen to play the same part as an atom of hydrogen, that the two bodies, in short, may be substituted the one for the other, and atom for atom; as experiment proves that 8 parts, in weight, of oxygen go to 1 of hydrogen, we are bound to conclude that the atom of oxygen weighs 8 times heavier than that of hydrogen;—that the atomic weight of oxygen is 8.

We will now assume that it takes 2 atoms of hydrogen to replace one of oxygen. As one of hydrogen is replaced by 8 of oxygen, 2 of hydrogen will require 16 of oxygen; this will lead us to the admission that the atom of oxygen weighs 16 times heavier than that of hydrogen;—that the atomic weight of oxygen is 16.

It thence follows that—according as the atom of oxygen is substituted for 1 or for 2 atoms of hydrogen—the atomic weight of the first of those two bodies is 8 or 16; whereas the equivalent—which only represents a simple relation of weight, irrespective of atoms—remains always equal to 8.

It is necessary to bear in mind that the numbers whereby the atoms of the different bodies are expressed have reference solely to their relative weights—not to their bulks, which are supposed to be equal in all cases.

Another important distinction to which we must call attention is this, that *compound bodies can have no atomic weight*: they have only a molecular weight.

Simple bodies have both a molecular weight and an atomic weight.

These two weights may be used indiscriminately in special cases when the molecule contains only one atom.

Two methods are commonly used to determine atomic weights: the one is founded on the fact that an atom is the smallest portion of a body which can exercise a reaction, the other is based upon the different specific heats. Both these methods are indispensable, as they cannot be always used indiscriminately.

*First Method.*—In order to determine the atomic weight of a simple body, it is necessary, in the first place, to know the molecular weights of that body in a free or uncombined state, and of all —or, at least, the greater number of the compounds which it forms; it is, moreover, requisite to ascertain the relative quantities which enter into the composition of these latter. We then choose, as the weight of the atom, the largest number that will exactly divide the weights of that body contained either in its free molecule or in that of its various compounds. For, in fact, a single molecule must contain a whole number of atoms, since these are indivisible; therefore, the weight of any number of atoms is necessarily always capable of being divided by that of a single atom.

One example will suffice to make this clearly understood. In comparing the weights of equal volumes of free hydrogen, hydrochloric acid, hydrobromic acid, hydriodic acid, hydrocyanic acid, hydrosulphuric acid, hydroselenic acid, hydrotelluric acid, ammonia, and so on, we find that the *molecular weights* of these different bodies, as compared with that of the *molecular* weight of hydrogen, taken as unity (and not with that of its atom, which we still suppose to be unknown), are as follows:—

| Names of Bodies. | Weights of Molecules compared with the Weight of a Molecule of Hydrogen = 1. | Quantitative Composition of the Molecule. | | |
|---|---|---|---|---|
| | | Amount of Hydrogen in a Molecule. | Quantities of: | |
| Pure hydrogen .. .. .. | 1 | 1 | 0 | other bodies. |
| Hydrochloric acid .. .. | 18·25 | ½ | 17·75 | chlorine. |
| Hydrobromic acid .. .. | 40·50 | ½ | 40 | bromine. |
| Hydriodic acid .. .. .. | 64·00 | ½ | 63·5 | iodine. |
| Hydrocyanic acid .. .. | 13·5 | ½ | 13 | carbon and nitrogen combined. |
| Water .. .. .. .. .. | 9 | 1 | 8 | oxygen. |
| Hydrosulphuric acid .. | 17 | 1 | 16 | sulphur. |
| Hydroselenic acid .. .. | 40·75 | 1 | 39·75 | selenium. |
| Hydrotelluric acid .. .. | 65·5 | 1 | 64·5 | tellurium. |
| Formic acid .. .. .. | 23 | 1 | 22 | carbon and oxygen combined. |
| Ammonia .. .. .. .. | 8·5 | ½ | 7 | nitrogen. |
| Phosphoretted hydrogen .. | 17 | ½ | 15·5 | phosphorus. |
| Arseniuretted hydrogen .. | 39 | ½ | 37·5 | arsenic. |
| Acetic acid .. .. .. .. | 30 | 2 | 28 | carbon and oxygen combined. |
| Ethylene .. .. .. .. | 14 | 2 | 12 | carbon. |
| Propionic acid .. .. .. | 37 | 3 | 34 | carbon and oxygen combined. |
| Alcohol .. .. .. .. | 23 | 3 | 20 | „ „ |
| Ether .. .. .. .. .. | 37 | 5 | 32 | „ „ |

From this Table it will be seen that the greatest common divisor of the numbers, ½, 1, ½, 2, 3, 5, which express the weights of hydrogen contained in the molecules of the different bodies, is ½; therefore ½ represents the atomic weight of hydrogen. All the weights in the foregoing Table refer to the molecule of hydrogen. If, however, we take as unity the weight of this atom instead of that of the molecule, the numbers would be doubled, as follows:—

| Names of Bodies. | Molecular Weights compared with the Weight of One Atom of Hydrogen. | Quantitative Composition of the Molecule. | | |
|---|---|---|---|---|
| | | Amount of Hydrogen in a Molecule. | Quantities of: | |
| Pure hydrogen .. .. .. | 2 | 2 | 0 | other bodies. |
| Hydrochloric acid .. .. | 36·5 | 1 | 35·5 | chlorine. |
| Hydrobromic acid .. .. | 81 | 1 | 80 | bromine. |
| Hydriodic acid .. .. .. | 128 | 1 | 127 | iodine. |
| Hydrocyanic acid .. .. | 27 | 1 | 26 | cyanogen. |
| Water .. .. .. .. | 18 | 2 | 16 | oxygen. |
| Hydrosulphuric acid .. | 34 | 2 | 32 | sulphur. |
| Hydroselenic acid .. .. | 81·5 | 2 | 79·5 | selenium. |
| Hydrotelluric acid .. .. | 131 | 2 | 129 | tellurium. |
| Formic acid .. .. .. | 46 | 2 | 44 | carbon and oxygen. |
| Ammonia .. .. .. .. | 17 | 3 | 14 | nitrogen. |
| Phosphoretted hydrogen .. | 34 | 3 | 31 | phosphorus. |
| Arseniuretted hydrogen .. | 78 | 3 | 75 | arsenic. |
| Acetic acid .. .. .. | 60 | 4 | 56 | carbon and oxygen. |
| Ethylene .. .. .. .. | 28 | 4 | 24 | carbon. |
| Propionic acid .. .. .. | 74 | 6 | 68 | carbon and oxygen combined. |
| Alcohol .. .. .. .. | 46 | 6 | 40 | carbon and oxygen. |
| Ether .. .. .. .. .. | 74 | 10 | 64 | „ „ |

And 1, being the greatest common divisor, would be the true atomic weight of hydrogen.

In the same manner, we can determine the atomic weights of other simple bodies; for instance,

nitrogen. For this purpose we must first examine the molecular weights and compositions of the different volatile compounds of nitrogen, as protoxide and binoxide of nitrogen, hyponitrous acid, hydrous and anhydrous nitric acid and ammonia; we can then form the following Table:—

| Names of Bodies. | Weight of Molecule compared with an Atom of Hydrogen = 1. | Amount of Nitrogen. | Amount of: |
|---|---|---|---|
| Protoxide of nitrogen .. | 44 | 28 | 16 oxygen. |
| Binoxide of nitrogen .. | 30 | 14 | 16 „ |
| Hyponitrous acid .. .. | 46 | 44 | 32 „ |
| Hydrated nitric acid .. | 63 | 14 | 49 „ and hydrogen combined. |
| Anhydrous nitric acid .. | 108 | 28 | 80 „ |
| Ammonia .. .. .. .. | 17 | 14 | 3 hydrogen. |
| Nitrogen .. .. .. .. | 28 | 28 | 0 other bodies. |

14, being the greatest common divisor of the numbers 14 and 28, becomes the atomic weight of nitrogen, and will remain so unless a new combination of that body be discovered, the molecule of which shall contain a quantity of that metalloid equal to a submultiple of 14.

*Second Method.*—This method is due to Dulong and Petit. The atomic weights of several bodies being already known, those savants found that the same amount of heat is always requisite in order to raise by 1 degree the weights of various simple bodies proportional to their atomic weights. Thus, to increase by 1 degree 25 grammes of sodium, 32 grammes of sulphur, 118 grammes of tin, 31 grammes of phosphorus, &c., one same quantity of heat is required, which, for the present, we will represent by the letter P.

P raises 23 grammes of sodium 1 degree. It is evident, then, that to raise 1 gramme—that is, 23 times less of that element—also 1 degree, 23 times less heat will be required, or $\frac{P}{23}$. Therefore, $\frac{P}{23}$ represents the calorific capacity of sodium.

In a like manner it will be found that the calorific capacity of sulphur is $\frac{P}{32}$, that of tin $\frac{P}{118}$, and that of phosphorus $\frac{P}{31}$.

It will be seen that the specific heats decrease when the atomic weights increase, and that in the same ratio; so that the atomic weights being 1, 2, 4, 8, 16, &c., the specific heats will be $\frac{1}{1}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, &c.

We are taught by arithmetic that if the two factors of a multiplication be so modified that the one becomes 2, 3, 4, 5 times less while the other becomes 2, 3, 4, 5 times greater, the product is invariable. We must, therefore, always obtain sensibly the same number when we multiply the specific heats of various bodies by their atomic weights.

Thus, the product of the atomic weight of sodium by its specific heat is $\frac{P \times 23}{23} = P$. The product of the atomic weight of sulphur by its specific heat is $\frac{P \times 32}{32} = P$. The constant number P has been numerically determined, and is sensibly equal to 6·666.

If it be required to find the atomic weight of a simple body, its specific heat must be ascertained. Let C represent the heat, and $x$ its unknown atomic weight, we have: $C \times x = 6{\cdot}666$; whence we derive $x = \frac{6{\cdot}666}{C}$. The atomic weight is found, therefore, by dividing the number 6·666 by the specific heat derived from experiment.

Dulong and Petit have enunciated this law by saying that the specific heats are inversely proportional to the atomic weights.

To enable the use of this method, it is necessary that the bodies whose specific heat we wish to ascertain, exist under similar conditions. Thus the specific heat of gases cannot be used to determine their atomic weights. But, in this case, the desired result is arrived at in a different manner.

M. Vœstyn discovered that, in compound bodies, each atom retains its specific heat. If the molecule of a compound body contains 2, 3, 4 simple atoms, the product of its specific heat by its molecular weight will be 2, 3, 4 times the constant number 6·666.

So that, supposing that the atomic weight of a gas be required, it must be made to enter into such a combination as will assume the solid state, and of which the specific heat must be ascertained. By multiplying the number representing that calorific capacity by the molecular weight of the compound, and dividing the product by 6·666, the quotient gives the number of atoms of which the molecule is composed. The analysis of the compound being made, and the atomic weight of one of its elements known, the atomic weight of the other can be readily deducted.

Let us assume, as an example, that it is sought by this process to find the atomic weight of oxygen: we combine it with hydrogen, and then determine the specific heat of the water thus formed, or rather, we know that it is equal to 1, since the specific heat of water has been taken as

the unity: on the other hand, the molecular weight of the water must be ascertained, and it will be found equal to 18. Now, as the number 18 contains 3 times 6, we arrive at the conclusion that the water contains 3 atoms; finally, it is shown by analysis that 18 of water contain 16 of oxygen, and 2 of hydrogen. We are, moreover, aware that the weight of an atom of hydrogen is 1; we must thence conclude that the atom of oxygen weighs 16. For, if it weighed less than 16, there would be more than one atom in a molecule of water, and, as the latter already contains 2 atoms of hydrogen, it would contain altogether more than 3 atoms, which would be in contradiction with the conclusions deduced from the calorific capacity of water.

It has been seen that, in lieu of dividing 18 by 6·666, we divided it only by 6. That is because the number P is not absolutely constant, but varies between 6 and 7: so that in selecting 6·666 we only chose the mean. This, however, does not in any way weaken either the law or the results derived from it. The specific heats are only approximate, because it is not possible to tell what quantity of caloric a body absorbs in order to expand as well as to become heated, a quantity which increases the specific heat found, and falsifies the result; but this slight divergence between theory and experiment offers no inconvenience: it tends, it is true, to render the atomic weights likewise only approximate; fortunately that approximation is sufficiently great to render the analysis of the compounds, into which enter the bodies of which the atomic weights are required, all-sufficient in completely establishing the latter.

If the atomic weight of silver were required, we should divide the number 6·666 by 0·05701, the specific heat of the metal, and thus we should obtain $\frac{6{\cdot}666}{0{\cdot}05701} = 117$; if, on the other hand, we combine silver and chlorine, and analyze the chloride of silver, we shall find that that compound contains 35·5 of chlorine to 108 of silver.

As 35·5 represents the atomic weight of chlorine, we may consider this latter to be combined with 1, 2, 3, 4 . . . atoms of silver. And, in these several hypotheses, the atomic weight of silver would be 108, 54, 27, . . &c.

Again, we may suppose the chloride of silver to contain only 1 atom of silver, to 2, 3, 4, 5, . . . atoms of chlorine, so that the quantity of silver in combination with 35·5 of chlorine would represent but $\frac{1}{1}$, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, . . . the weight of its atom. In these several hypotheses the atomic weight of silver would be 216, 324, 432, 540, . . . &c.

Other hypotheses may be added to the above; but, be they what they may, they will always give for the atomic weight of silver values that differ considerably from the number 117, found by means of the specific heat. There is but one supposition which yields a value in approximate harmony with that number, it is the one whence we deduced 108 as the atomic weight: 108 must, therefore, be regarded as the true atomic weight of silver.

The object of chemical notation is to represent the various bodies known by means of brief formulæ which shall indicate at once their molecular weight, and their composition both as to quality and quantity; thus enabling the sense of the different reactions that take place to be better understood.

In the construction of these formulæ a symbol has been adopted that represents the atom —not the molecule—of each simple body; such are the symbols used in the Table. These symbols are generally obtained by taking the initial letter of the name of the body, thus: O for oxygen, S for sulphur, and so on. When the names of several bodies commence with the same letter, the first letter is then taken to designate that body only that has been longest known; whereas, for the symbol of the others, the *two* first letters of their name are used. For instance, sulphur, selenium, silicium, strontium, beginning each with an S, S signifies sulphur, while Se represents selenium, Si silicium, and St strontium.

There are, however, some exceptions to this rule: occasionally, instead of using the two first letters, the first and one of the letters in the body of the word are taken. Thus, arsenic is expressed by As, stannum (tin) by Sn, stibium (antimony) by Sb, and hydrargyrum (mercury) by Hg.

Finally, in the same way that some of the symbols are taken from the Latin, like the three last, others are borrowed from the German. Thus, the symbol of tungsten is W, from the German Wolfram.

All simple bodies being indicated by a symbol that expresses not only their nature, but also their atomic weight, nothing is easier than to represent a compound molecule. The only thing needed is to write down, side by side, the several constituent atoms, adding above each one an exponent indicative of its number. When that number is equal to 1, the exponent is dispensed with. Thus, $S O^3$ implies a compound molecule formed of 1 atom of sulphur and 3 atoms of oxygen.

In symbolic writing it has been agreed to place the most electro-positive of the several components always first. But this rule is only strictly followed for those compounds that contain but two elements.

It is clear that the formulæ of which we are now speaking represent the qualitative composition of bodies. It is also clear that they represent their molecular weights. Since a molecule can have no other weight than the sum of the weights of the atoms contained in it, in order to know how much it weighs, it will suffice to multiply the atomic weight of each element by its exponent, and add together the products. Thus, the formula of glycerine being $C^3 H^8 O^3$, its molecular weight will be equal to

| | |
|---|---|
| the weight of 3 atoms of carbon .. .. .. .. | $3 \times 12 = 36$ |
| + the weight of 8 atoms of hydrogen .. .. .. | $8 \times 1 = 8$ |
| + the weight of 3 atoms of oxygen .. .. .. .. | $3 \times 16 = 48$ |
| Total .. .. | 92 |

Finally, these formulæ represent likewise the centesimal composition of bodies. Knowing the quantity of the various elements contained in a certain weight of the compound—that of its molecule, we arrive, by means of a simple proportion, at the knowledge of its centesimal composition.

For example, supposing that we wish to find the centesimal composition of acetic acid; we deduce from its formula, $C^2 H^4 O^2$, in the first place, that the molecule of this acid weighs 60, and that it contains

2 atoms = 24 of carbon,
4 atoms = 4 of hydrogen,
and 2 atoms = 32 of oxygen.

We next lay down the three proportions:—

1st. $60 : 24 :: 100 : x$, where $x = \frac{24 \times 100}{60} = \frac{24 \times 10}{6} = 40.$

2nd. $60 : 4 :: 100 : x$, where $x = \frac{4 \times 100}{60} = \frac{4 \times 10}{6} = 6{\cdot}666.$

3rd. $60 : 32 :: 100 : x$, where $x = \frac{32 \times 100}{60} = \frac{32 \times 10}{6} = 53{\cdot}333.$

We now know in what manner, by the aid of a formula, it is possible to learn the quantitative and qualitative composition, as well as the molecular weight, of the compound which it represents. It remains to be seen how, with a given body, the formula is to be established; it is the other side of the problem.

To establish the formula of a compound body, we first of all ascertain by analysis its centesimal composition; then we determine its molecular weight. Our next step is, by a series of proportions, to find out the composition of a certain weight of that substance known to represent its molecular weight. After which we divide the quantities of its several elements by their atomic weights; the quotient shows how many atoms there are of each. Finally, we only have to write down, side by side, the symbols expressing the different atoms, beginning with the most electro-positive, and to surmount those symbols by an exponent indicating the number of the atoms.

Let us apply this rule to an example, and suppose that it be required to establish the formula for propionic acid. We analyze the acid, and we find that it contains 48·648 centesimals of carbon, 43·243 of oxygen, and 8·108 of hydrogen.

We next look for its molecular weight, and find it equal to 74. Having done that, we lay down the three proportions:—

1st. $100 : 48{\cdot}648 :: 74 : x$, where $x = 35{\cdot}999$, or nearly 36.
2nd. $100 : 43{\cdot}243 :: 74 : x$, where $x = 31{\cdot}999$, or nearly 32
3rd. $100 : 8{\cdot}108 :: 74 : x$, where $x = 5{\cdot}999$, or nearly 6.

So that one molecule of propionic acid weighs 74, and contains 36 of carbon, 32 of oxygen, and 6 of hydrogen.

The weight of one atom of carbon is 12; if, then, we divide the weight of that body contained in one molecule of propionic acid, that is 36, by 12, we shall have the number of its atoms; and, as $\frac{36}{12} = 3$, we conclude that it contains 3 atoms of carbon.

In like manner, the weight of one atom of oxygen being 16, we divide the weight of oxygen contained in the molecule by that number; that is, $\frac{32}{16} = 2$: therefore, propionic acid contains 2 atoms of oxygen.

Finally, one atom of hydrogen weighs 1, and as there are 6 of hydrogen, and $\frac{6}{1} = 6$, we conclude that propionic acid contains 6 atoms of that element.

Hence the formula for propionic acid is $C^3 H^6 O^2$.

It is sometimes necessary to indicate that a certain number of molecules of a same body take part in a reaction. It is then customary to place at the left of the formula a coefficient, to express that number. Thus, to signify 3 molecules of propionic acid, we write $3\ C^3 H^6 O^2$.

Lastly, in order to render an exact account of the reactions, it is the practice to represent them by means of equations. In these equations the first side contains the formulæ of the different bodies entering into reaction, preceded by a coefficient indicating how many molecules react; and the second side, which is separated from the first by the sign =, contains the formulæ of the products formed by the reaction. As nothing is lost during chemical action, it is clear that the second side of the equation must contain strictly all the atoms that existed in the first, only differently grouped.

To give an example of a chemical equation, we will represent the reaction which gives rise to chloride of potassium, K C l, by means of hydrochloric acid, H C l, and of potassium K H O.

$$\underset{\text{Potassium.}}{KHO} + \underset{\text{Hydrochloric acid.}}{HCl} = \underset{\text{Chloride of potassium.}}{KCl} + \underset{\text{Water.}}{H^2O}.$$

The atom of potassium, the two atoms of hydrogen, the atom of oxygen, and the atom of chlorine that compose the first side, are all found in the second side, but grouped in a different way.

The following Table contains a complete list of the elementary bodies known at present (1869). Every description of matter which has been examined is made up of these 65 elements, either combined together to form compounds, or in an uncombined or free state.

| Names of Elements. | New Symbols. | Old Symbols. | Hydrogen = 1. New Atomic Weights. | Hydrogen = 1. Atomic Weights of Berzelius. | Hydrogen = 1. Atomic Weights of Gerhardt. | Atomic Volumes. | Weight of a Cubic Foot in Ounces Avoirdupois. Water = 1000 oz. | Specific Gravity. Water = 1. When water = 1000, the decimal point is to be placed to the Right, three places of Figures. |
|---|---|---|---|---|---|---|---|---|
| Aluminium | Al | Al | 27·5 | 27·39 | 13·75 | 5·3 | 2670 | 2·5—2·67, Wöhler; 2·67, Deville. |
| Antimony | Sb | Sb | 122 | 129·24 | 122 | 17·9 | 6720 | 6·72, Marchand and Scheerer; Kopp. |
| Arsenic | As | As | 75 | 75·22 | 75·22 | 13·3 | 5670 | 5·63, Karsten; 5·67, Herapath. |
| Barium | Ba | Ba | 137 | 137·06 | 68·5 | .. | .. | |
| Bismuth | Bi | Bi | 210 | 213·20 | 210 | 21·2 | 9800 | 9·80, Marchand and Scheerer; 9·78, Kopp. |
| Boron | B | B | 11 | 21·82 | 10·9 | .. | .. | |
| Bromine | Br | Br | 80 | 80·10 | 80 | 25·8 | 3190 | *Liquid:* 3·19, Pierre; 2·99, Löwig. |
| Cadmium | Cd | Cd | 112 | 111·66 | 56 | 6·5 | 8690 | 8·69, Stromeyer; 8·45, Kopp. |
| Cæsium | Cs | Cs | 133 | .. | .. | .. | .. | |
| Calcium | Ca | Ca | 40 | 40·32 | 20 | 12·6 | 1580 | 1·58, Bunsen. |
| Carbon | C | C | 12 | 12·04 | 22 | 3·4 | 3520 | *Diamond:* 3·52, Brisson. |
| Cerium | Ce | Ce | 92 | .. | .. | .. | .. | |
| Chlorine | Cl | Cl | 35·5 | 35·52 | 35·5 | 26·7 | 1330 | *Liquid:* 1·33, Faraday. |
| Chromium | Cr | Cr | 52·5 | 52·70 | 26·26 | 3·8 | 7010 | 7·01, Bunsen and Frankland. |
| Cobalt | Co | Co | 59 | 59·07 | 29·5 | 3·5 | 8510 | 8·49, Brunner; 8·51, Berzelius. |
| Copper | Cu | Cu | 63·5 | 63·39 | 31·75 | 3·6 | 8950 | 8·95, Marchand and Scheerer; 8·93, Kopp. |
| Didymium | Di | Di | 95 | .. | .. | .. | .. | |
| Erbium | Erb | E | .. | .. | .. | .. | .. | |
| Fluorine | Fl | F | 19 | 18·70 | 19 | .. | .. | |
| Glucinum | Gl | Gl | 14 | .. | .. | 2·2 | 2100 | 2·1, Debray. |
| Gold | Au | Au | 197 | 196·98 | .. | 10·2 | 19340 | 19·34. G. Rose; 19·26, Brisson. |
| Hydrogen | H | H | 1 | 1 | 1 | .. | .. | |
| Indium | In | In | 35·9(?) | .. | .. | .. | .. | |
| Iodine | I | I | 127 | 127·08 | 127 | 25·7 | 4950 | 4·95, Gay-Lussac |
| Iridium | Ir | Ir | 198 | 197·44 | 98·56 | 4·5 | 21800 | 21·80, Hare. |
| Iron | Fe | Fe | 56 | 56·17 | 28 | 3·6 | 7840 | 7·84, Broling; 7·79, Karsten. |
| Lanthanum | La | La | 92·8 | .. | .. | .. | .. | |
| Lead | Pb | Pb | 207 | 207·47 | 103·5 | 9·2 | 11390 | 11·39, Karsten; 11·33, Kopp. |
| Lithium | Li | Li | 7 | 13·08 | 7 | 11·9 | 590 | 0·59, Bunsen. |
| Magnesium | Mg | Mg | 24 | 25·34 | 12 | 6·9 | 1740 | 1·74, Bunsen; 1 70, Kopp. |
| Manganese | Mn | Mn | 55 | 55·23 | 27·5 | 3·5 | 8030 | 8·03, Bachmann; 8·01, John. |
| Mercury | Hg | Hg | 200 | 200·52 | 100 | 7·4 | 13600 | *Liquid:* 13·60, Regnault, Kopp. |
| Molybdenum | Mo | Mo | 96 | 95·53 | 48 | 5·3 | 8630 | 8·62—8·64, Buchholz. |
| Nickel | Ni | Ni | 59 | 59·19 | 29·5 | 3·4 | 8820 | 8·60. Brunner; 8·82, Tupputi. |
| Niobium | Nb | Nb | 94 (?) | .. | .. | .. | .. | |
| Nitrogen | N | N | 14 | 14·02 | 14 | .. | .. | |
| Norium | No | No | .. | .. | .. | .. | .. | |
| Osmium | Os | Os | 199 | 199·13 | .. | .. | .. | |
| Oxygen | O | O | 16 | 16 | 16 | .. | .. | |
| Palladium | Pd | Pd | 106·5 | 106·64 | .. | 4·6 | 11800 | 11·80, Wollaston. |
| Phosphorus | P | P | 31 | 31·41 | 31 | 16·8 | 1840 | *Yellow:* 1·84, Schrötter; 1·83, Kopp. |
| Platinum | Pt | Pt | 197·5 | 197·44 | 98·5 | 4·6 | 21500 | 21·5, Wollaston, Berzelius. |
| Potassium | K | K | 39 | 78·47 | 39 | 45·6 | 860 | 0·86, Gay-Lussac and Thenard. |
| Rhodium | Rh | Rh | 104·4 | 104·48 | .. | 4·7 | 11200 | 11·0, Wollaston; 11·2, Cloud. |
| Rubidium | Rb | Rb | 85·4 | .. | .. | .. | .. | |
| Ruthenium | Ru | Ru | 104·4 | .. | .. | .. | .. | |
| Selenium | Se | Se | 79·5 | 79·37 | 79·5 | 18·4 | 4280 | *Amorphous:* 4·28, Schaffgotsch. |
| Silicon | Si | Si | 28 | 44·51 | .. | 11·2 | 2490 | 2·49, Wöhler. |
| Silver | Ag | Ag | 108 | 216·29 | 108 | 10·2 | 10570 | 10·4, Karsten; 10 57, G. Rose. |
| Sodium | Na | Na | 23 | 46·43 | 23 | 23·7 | 970 | 0·97, Gay-Lussac and Thenard. |
| Strontium | Sr | Sr | 87·5 | 87·48 | 43·75 | 17·2 | 2540 | 2·54, Bunsen. |
| Sulphur | S | S | 32 | 32·17 | 32 | 15·2 | 2070 | *Trimetric:* 2·07, Marchand and Scheerer, Kopp. |
| Tantalum | Ta | Ta | 137·6 | .. | .. | .. | .. | |
| Tellurium | Te | Te | 129 | 128·48 | 129 | 20·6 | 6240 | 6·24, Berzelius; 6·18, Löwe. |
| Terbium | Tr | Tr | .. | .. | .. | .. | .. | |
| Thallium | Tl | Tl | 204 | .. | .. | .. | .. | |
| Thorium | Th | Th | .. | .. | .. | .. | .. | |
| Tin | Sn | Sn | 118 | 117·83 | 59 | 16·2 | 7300 | 7·29, Karsten; 7·30, Kopp. |
| Titanium | Ti | Ti | 50 | 48·3 | 25 | .. | .. | |
| Tungsten | W | W | 184 | 190·44 | 92 | 5·3 | 17900 | 17·2, Allen and Aiken; 17·5—18·3, Wöhler. |
| Uranium | U | U | 120 | 118·88 | 60 | 3·3 | 18400 | 18·4, Péligot. |
| Vanadium | V | V | 137 | 137·32 | .. | .. | .. | |
| Yttrium | Yt | Y | 68 | .. | .. | .. | .. | |
| Zinc | Zn | Zn | 65·2 | 65·16 | 32·6 | 4·6 | 7130 | 7·13, Kopp; 7·1—7·2, Bolley. |
| Zirconium | Zr | Zr | 89·6 | 67·26 | .. | .. | .. | |

The succeeding tabulated form shows at one view where the ordinary substances, not agreeing with the required alphabetical order, are placed, and from what words their respective symbols are taken.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Aluminium | Al | Hydrargyrus (mercury) | Hg | Rhodium | Rh |
| Argentum (silver) | Ag | Hydrogen | H | Rubidium | Rb |
| Arsenic | As | Indium | In | Ruthenium | Ru |
| Aurum (gold) | Au | Iodine | I | Selenium | Se |
| Barium | Ba | Iridium | Ir | Silicon | Si |
| Bismuth | Bi | Kalium (potassium) | K | Stannum (tin) | Sn |
| Boron | B | Lanthanum | La | Stibium (antimony) | Sb |
| Bromine | Br | Lithium | Li | Strontium | Sr |
| Cadmium | Cd | Magnesium | Mg | Sulphur | S |
| Cæsium | Cs | Manganese | Mn | Tantalum | Ta |
| Calcium | Ca | Molybdenum | Mo | Tellurium | Te |
| Carbon | C | Natrium (sodium) | Na | Terbium | Tr |
| Cerium | Ce | Nickel | Ni | Thallium | Tl |
| Chlorine | Cl | Niobium | Nb | Thorium | Th |
| Chromium | Cr | Nitrogen | N | Titanium | Ti |
| Cobalt | Co | Norium | No | Uranium | U |
| Cuprum (copper) | Cu | Osmium | Os | Vanadium | V |
| Didymium | Di | Oxygen | O | Wolfram (tungsten) | W |
| Erbium | Erb | Palladium | Pd | Yttrium | Yt |
| Ferrum (iron) | Fe | Phosphorus | P | Zinc | Zn |
| Fluorine | Fl | Platinum | Pt | Zirconium | Zr |
| Glucinum | Gl | Plumbum (lead) | Pb | | |

*Prefixes and Affixes.*—Hypo-. This term is used to indicate that the substance to which it is applied contains less oxygen than the other substance from which the name is derived; thus *Hyponitric acid* contains less oxygen than nitric acid. *-ous* is used to imply less oxygen than the termination, *-ic;* thus nitr*ous* oxide contains half as much oxygen for its nitrogen as nitr*ic* oxide. Many of the elements are capable of uniting with other elements in several different proportions to form chemical compounds. Sulphur, for example, is specially apt to form more than one compound with a single element. When sulphur unites with a metal, the compound formed is called a sulph*ide,* just as a compound of oxygen and a metal is called an oxide, or one of chlorine and a metal a chloride,—the termination, *-ide,* which always indicates combination, being added to the first syllable of the word sulphur, or oxygen, or chlorine, and the new word ending in *ide* being then connected with the name of the metal, as in the case of sulphide of copper. But when, as in the case of calcium, there are several distinct sulphides, it is customary to distinguish one from the other by means of various Latin and Greek prefixes. Thus the compound which contains one atom of sulphur and one atom of calcium is the proto-sulphide, or simply the sulphide of calcium, the prefix *proto-* being derived from the Greek word for first; the compound which contains two atoms of sulphur to one of calcium is the bisulphide of calcium, from the Latin for twice; and in like manner we have a tersulphide, containing three atoms of sulphur to one of calcium, and a quinquisulphide containing five atoms of sulphur. The compound containing the highest proportion of sulphur is often called the *per*sulphide. A good custom is to designate the compounds which contain more sulphur than the protosulphide by prefixes of Latin origin, and to distinguish those which may contain less sulphur than the protosulphide by means of Greek prefixes; thus, if there were a compound of two atoms of calcium and one of sulphur, it would properly be called a *di*-sulphide of calcium, the prefix being from the Greek δις. The same prefixes are used in an analogous manner in connection with the words oxide, chloride, bromide, iodide, and the similar words ending in *ide.*

Many modern writers on chemistry employ a notation which we append. Some of the symbols and contractions of this notation are embodied in the notation we have just explained.

One equivalent of oxygen;—written above a symbol representing an element, and repeated to indicate two, three, or more equivalents; thus, $\dot{F}e$ denotes a compound of one equivalent of oxygen with one of iron; $\dot{\bar{S}}$ a compound of three equivalents of oxygen with one of sulphur.

' One equivalent of sulphur;—used in the same manner as the preceding; thus, $\dot{F}e$ denotes a compound of two equivalents of sulphur and one of iron.

A dash drawn across a symbol having either of the foregoing signs above it, denotes that two equivalents of the substance represented by the symbol are joined with the number of equivalents of oxygen or sulphur indicated by the dots or commas; thus, $\ddot{\bar{F}}e$ represents a compound of two equivalents of iron and three of oxygen, forming sesqui-oxide of iron.

\+ indicates, in organic chemistry, a base or alkaloid, when placed above the initial letter of the name of the substance; as, $\dot{M}$, morphine; $\dot{Q}$, quinine.

— indicates, in organic chemistry, an acid, when placed above the initial letter of the name of the acid; as, $\bar{C}$, citric acid; $\bar{T}$, tartaric acid.

Each symbol, when used singly, always indicates a single atom or equivalent of the substance represented by it; thus, O stands for one atom or equivalent of oxygen, C for a single equivalent of carbon, and the others in like manner. A compound body made up of single equivalents of its constituents is represented by the two symbols of the respective constituents written side by side;

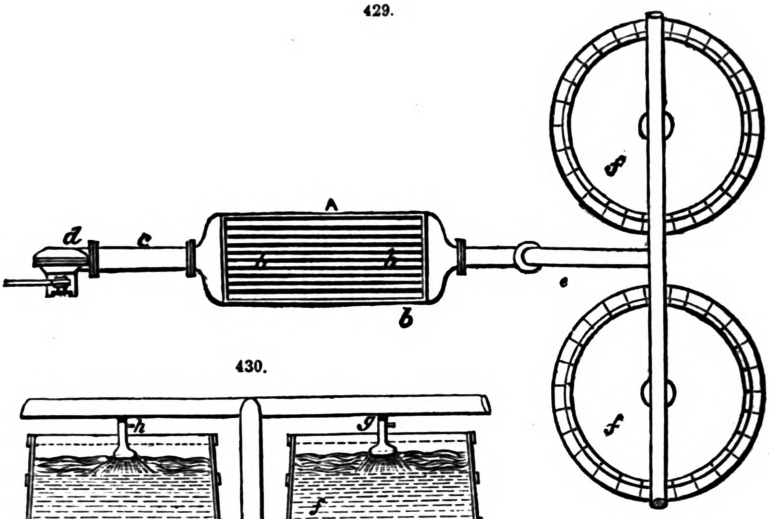
as, H O, a compound of one equivalent of hydrogen with one of oxygen, forming water. To express more than one atom or equivalent of a substance, a number is used, either prefixed to the symbol, or, more commonly, written after it, below the line; as, 2 O, or $O_2$, two equivalents of oxygen.

A secondary compound, as a salt, is indicated by writing the symbols of the constituent compounds one after another, with the sign + between them, the symbol of the base being always placed first; thus, Ca O + C $O_2$ represents carbonate of lime. A comma is frequently used instead of the sign +, commonly to express a more intimate union than would be expressed by that sign. The period is also sometimes used to indicate a union more intimate than that denoted by the sign +, but less so than that implied by a comma. A number written before the symbol of a compound designates a corresponding number of equivalents of that compound; as, 3 S $O_3$, three equivalents of sulphuric acid. When the formula of the quantity contains several terms, those to which the figure applies are included in parentheses or brackets, to which the figure is prefixed; as 3 (Ca O + S $O_3$), three equivalents of sulphate of lime. See EQUIVALENTS. HEAT. ISOMORPHISM. MOLECULAR VOLUME.

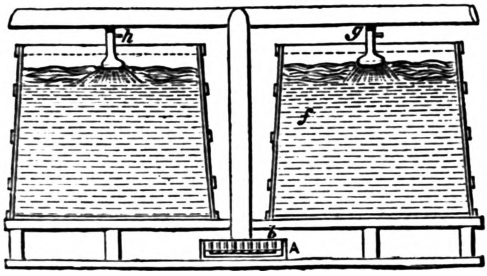
ATTEMPERATOR, IN BREWING. FR., *Attempérateur*; GER., *Eine Vorrichtung um eine gleichmässige Temperatur zu behalten*; ITAL., *Regolatore della temperatura*; SPAN., *Regulador de temperatura*.

The attemperator invented by A. B. Walker is shown at A, Figs. 429, 430, and consists of a rectangular frame, in which a series of flattened tubes *b*, *b*, are arranged side by side, with spaces

429.




430.




of about 5 in. between them. The spaces between the tubes are filled with spring-water, ice, or any freezing mixture of salts or acids. At one end the tubes are connected by the pipe *c*, to the fan *d*; at the opposite end they are connected to the pipe *e* which leads up to the fermenting-tuns *f*, branching off directly over each tun, and having a vertical tube *g*, pierced at the bottom with small holes for the exit of air. The supply of air to each tun is regulated by the slide *h*, so as to suit the progress of the fermentation. As soon as the fermentation commences, and the yeast begins to form on the surface of the wort, the fan is put in motion, and a current of air is thus driven through the tubes of the attemperator, and caused to pass over the surface of the wort until the fermentation is completed.

This atmospheric attemperator has been applied to the manufacture of malt, so that malt may be made in summer as well as in winter. Hitherto it has been impracticable to make malt in

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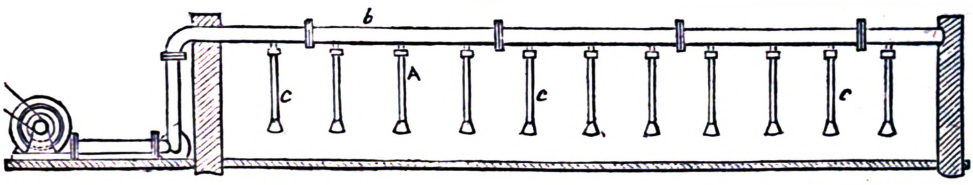


the summer equal to that made in winter, or, in fact, to make it at all in the summer, owing to the unsuitability of temperature. Fig. 431 shows the application to malting-rooms: A is the malting-

room; *b*, pipes leading from the attemperator directly through the malting-room, a few feet above the floor; *c c*, flexible tubes attached to the pipes, *b*, with rose perforated caps at the ends. Whilst the malt is on the floor in process of germination, the temperature of the room is regulated to that degree of temperature best suited for malting, by currents of attemperated air from the attemperator distributed over the surface of the malt on the floor.

Fig. 432 represents the attemperator invented by Joshua Crockford, as fixed to a wooden mash-tun with sliding side-doors and fixed roof, such as is largely used in Burton breweries. It consists

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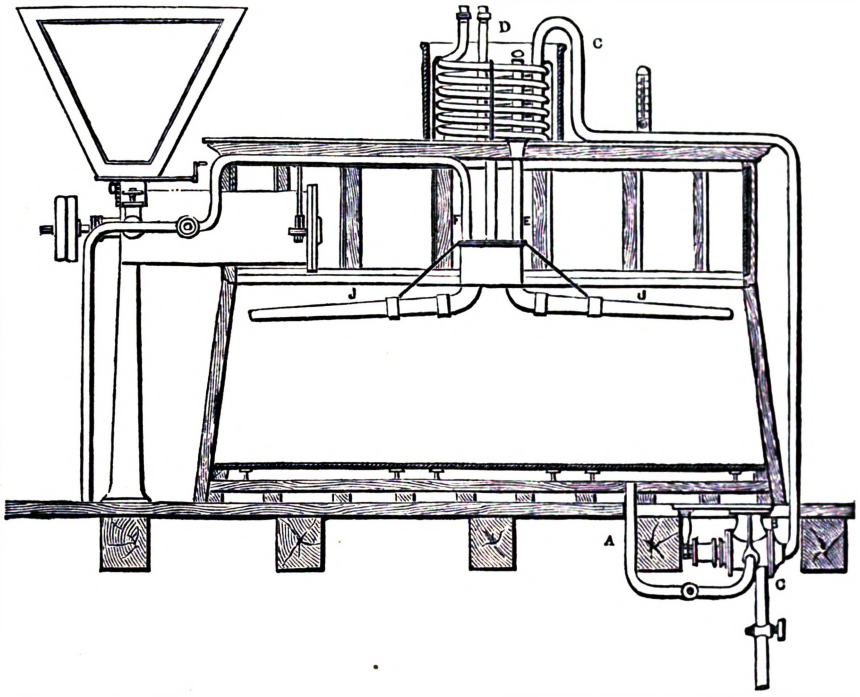



of a circular vessel, D, fixed on the top of the mash-tun, this vessel containing a coiled steam-pipe, and being fitted with suitable pipes for conducting the wort into and out of it. When it is desired to raise the temperature of the mash, the wort is drawn from the tun by the pipe, A; and the centrifugal-pump, B, being set in action, it is raised into the vessel, D, through the pipe, C. There it is heated by the action of the steam in the coiled pipes; and then it is led down through the pipe, E, to the central vessel of the sparger, J, which distributes it over the goods. It will be noticed that the pipe, C, conducts the wort to the bottom of the vessel, D, whilst the pipe, F, draws off the wort from near the surface, where it is of course hottest. The pipe, F, is for admitting the ordinary supply of hot liquor to the *sparger*.

So long as the pump, B, is in action, a constant current is maintained through the goods, the wort being drawn off at the bottom, heated, and again sparged on the top continually. By the use of this attemperator, the temperature of the mash can be kept at any desired point for any length of time; and in the case of small brewings, where the loss of heat, from radiation and other causes, is proportionately very great, it is particularly valuable.

ATTIC. Fr., *Grenier, Mansarde*; Ger., *Der Uebersatz*; Ital., *Attico*; Span., *Bazo tejado*.

See Building.

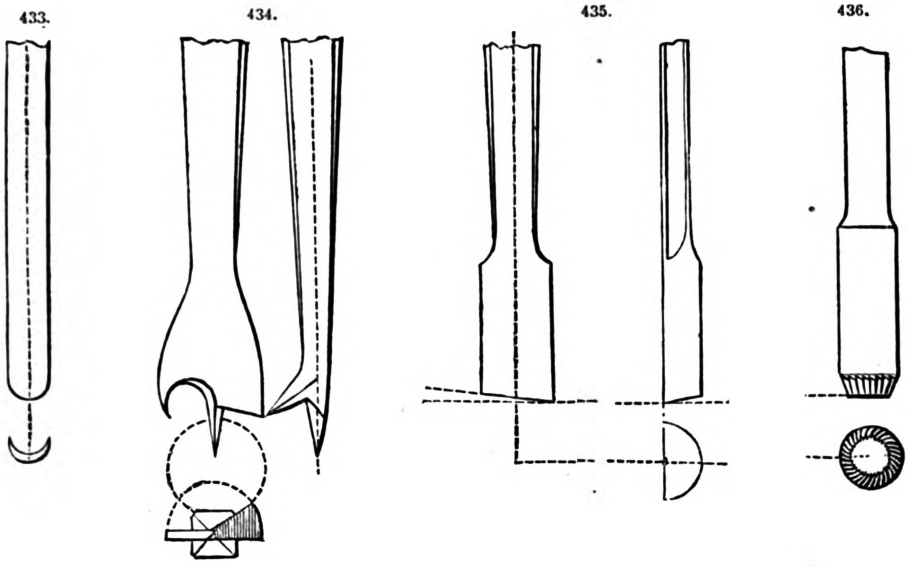
ATWOOD'S MACHINE. Fr., *Machine d'Atwood*; Ger., *Atwood Maschine für Anzeige von freian Fall der Körper*; Ital., *Macchina d'Atwood*; Span., *Maquina Attwood*.

See Acceleration.

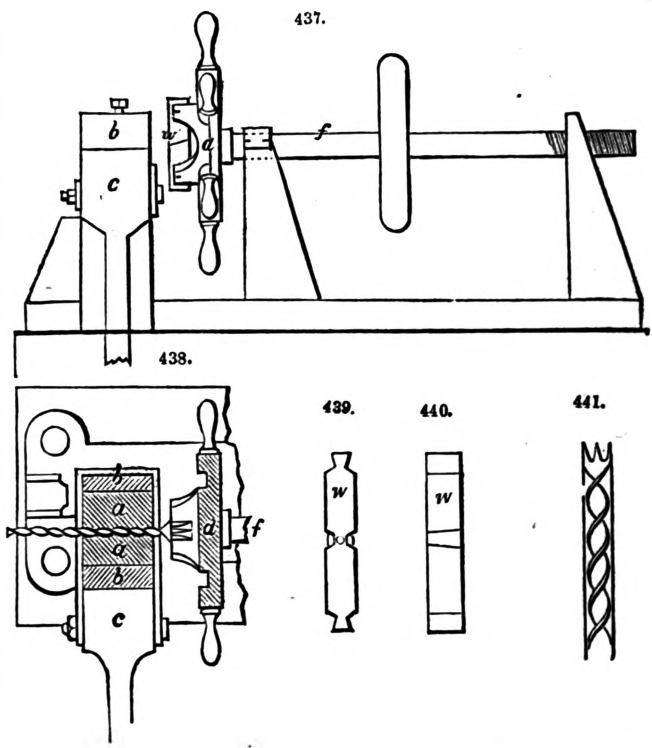
AUGER. Fr., *Tarière*; Ger., *Zimmermannsbohrer*; Ital., *Trivella*; Span., *Haladra*.

An *auger* is an instrument for boring holes, chiefly in wood. It consists of a long shank or axis, having a cutting-edge at one end, and usually a handle placed crosswise at the other, by which it is turned with both hands. A *pod-auger* has a straight channel or groove, like the half of a bean-pod. A *screw-auger* has a twisted blade, by the spiral groove of which the chips are discharged. Peculiar augers are employed, termed *ground-augers*, for boring *artesian wells*, or perforating soils or rocks, instruments of this sort consist of a handle for working, a rod which may be lengthened as the perforation extends, and a bit, mouth, or cutting-piece, resembling the bit of a common auger, for soils or soft rocks; and a chisel for harder rocks. A *bit* is a name common to all exchangeable boring tools; for wood, bits are generally applied by means of a crank-formed handle, known as the carpenter's *brace*. The smaller tools used for metal, and applied by the *bow-drill*, *ratchet-brace*, lathe, or drilling-machine, are termed drills, or *drill-bits*. The particular names used to designate *bits* are, in most cases, derived from their forms and the purposes for which they are employed. For wood, bits termed *shell-bits* are numerous; the simplest form is

shown in Fig. 433, which is shaped like a *gouge*, with the piercing end sharpened to a semicircular edge, for shearing the fibres around the circumference of the hole. When large, the *shell-bit* is termed a *gouge-bit*. Sometimes the piercing end is drawn to a radial point, and it is then termed a *spoon-bit*, of which the cooper's *dowel-bit* and the *table* or *furniture bit* are examples. When the




end is bent into a semicircular form horizontally, it is then termed a *duck-nose bit*. The *centre-bit*, shown in Fig. 434, is another typical form, in which the end is flat, provided with a centre point or pin, filed triangularly, which serves as a guide; the *centre-bit* has also a shearing-edge, or *nicker*, serving to cut the fibres round the margin of the hole, and a broad chisel-edge, or cutter, to pare away and remove the wood within the circle defined by the nicker. The *plug centre-bit*, used chiefly for making countersinks for cylinder-headed screws; the *button-tool*, which retains only the centre-pin and nicker, and is used for cutting out discs of leather, and of similar substances; the *flute-drill*, the *cup-key drill*, the wine-cooper's bit, are all modifications of the *centre-bit*. The *half-round bit*, shown in Fig. 435, is employed in enlarging holes in metal, and is usually fixed vertically, or worked by a lathe. The cutting end of this bit is ground with an inclined plane, from 3° to 6° from the perpendicular, according to the hardness of the metal to be bored. The *rose-bit* is shown in Fig. 436; it is cylindrical, and terminates in a truncated cone, the oblique surface of which is cut into teeth, like the *rose-countersink*, of which it is a modification. The *rose-bit* is often used for enlarging holes of considerable depth in metals.




Figs. 437, 438, 439, 440, 441, refer to Ransom Cook's machine for turning the lips of augers. In using this machine the cam-lever *c* is first raised to nearly a vertical position, thus allowing the clamps *b* to open. An auger or bit, with the lips shaped as shown in Fig. 441, being red-hot, is placed in one of the crimping-dies *a*, with the lips projecting beyond the die, and towards the wrench, Figs. 437, 438. The upper end of the cam-lever is then brought quickly down, thus forcing the other crimping-die against the auger, and firmly holding it between the two dies. A quick turn is given to the screw-shaft *f*, which brings the wrench in the hub of the wrench-wheel *d*

into an embrace with the end of the auger, the centre of which enters the hole in the wrench, while the lips pass into the slots on its side. One of the handles of the wrench-wheels is then seized by the operator, and turned towards himself, when the wrench, keeping the auger straight by means of its hold of the centre, turns or bends the lips into the desired position, both being turned at the same time and to the same angle, while the shoulders of both are left in the same line.

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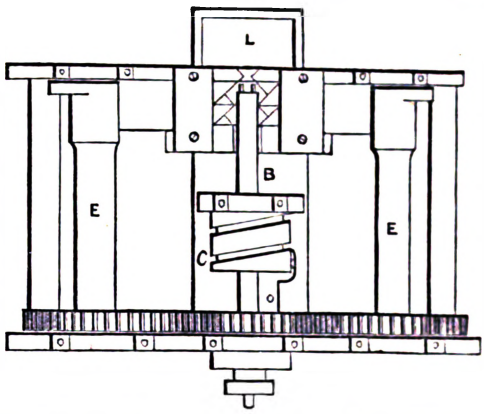


Grier and Boyd's machine for making auger-bits is shown in Fig. 442. The revolving and longitudinally-moving shaft L B, has a recess in its end for holding and twisting the blank, in connection with a series of dies arranged to clasp and hold the auger as fast as it is twisted; thus completing the process in one operation. The rotating-shaft B has a hole in it made longitudinally, of proper size and form, to receive the blank and hold it while being twisted and drawn out. The tongs L, having suitably constructed jaws, act in combination with the shaft B. C is a screw so arranged as to impart to the shaft B an intermittent longitudinal movement during the operation of twisting the blank, so that both twisting the blank and setting the lips are done in one operation.

Fig. 443 represents a machine for swaging the heads of screw-augers, invented by R. Jennings. The jaws of the gripping-dies are arranged vertically—one stationary, and the other movable; their faces grasp the twisted auger, and present the upper end to a hammer, which *swages* the points and lips at one blow. The heading-die is operated by the rotating-shaft B, through the medium of the loose driving-wheel E, provided with the pins *g*, the sliding-wheel F, placed on a sliding-rod H, and the fixed inclined lip *a*. The forming-die consists of the portions I, I, D, constructed and arranged as shown in Fig. 443. The heading-die D, mould L, toggle M, and operating mechanism, are so arranged that the driving-shaft B may, at the will of the operator, be connected with, or disconnected from, the continually rotating driving-wheel E.

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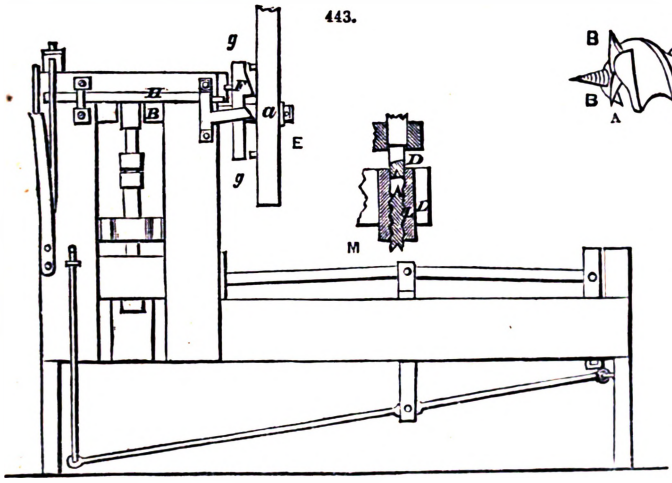


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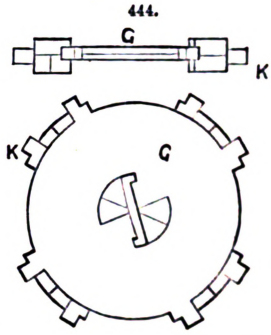
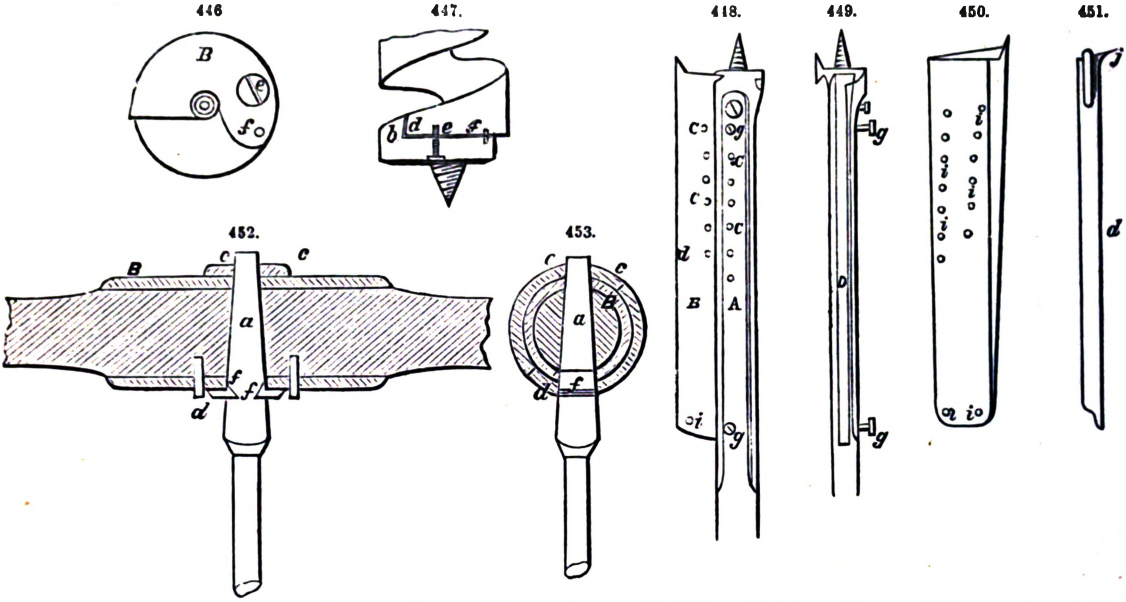



Fig. 444 illustrates the principles upon which a simple and ingenious machine, for forming the twist of auger-blanks, is constructed. This device, patented by Mary Tower, consists of a series of pairs of circular metallic plates, G, K, superimposed on each other, each plate having a peculiarly shaped mortice through the centre, and provided also with projecting and overlapping studs upon its periphery. When these plates are arranged in certain positions, the central mortices correspond with each other, and admit the flat bar of metal, previously heated, of which the auger is to be made; the upper plate is then turned round, with a continuous movement, until each plate has, by means of contact of the projecting studs with each other, been forced to assume the position required for imparting to the metal the necessary twist.

Jennings' double-twisted pod-auger is shown in Fig. 445; this instrument has two *floor-lips* B, B, which project beyond the positions in which they have heretofore been placed; and the spur *a*, instead of being situated at the outer front corner of the cutting-edge of the floor-lip, where the latter, from its necessary thinness, is weakest, is projected from its hinder part, or heel, where it is strongest. A new relation between the cutting-edge of the floor-lip and the spur is thus effected, so that the one does not interfere with the operation of the other. Hence the cutting-edges of a double-twist auger-bit are so formed, that the cutting-edges of the scorers and chisel do not intersect the worm or helix of the shaft A at the same point.

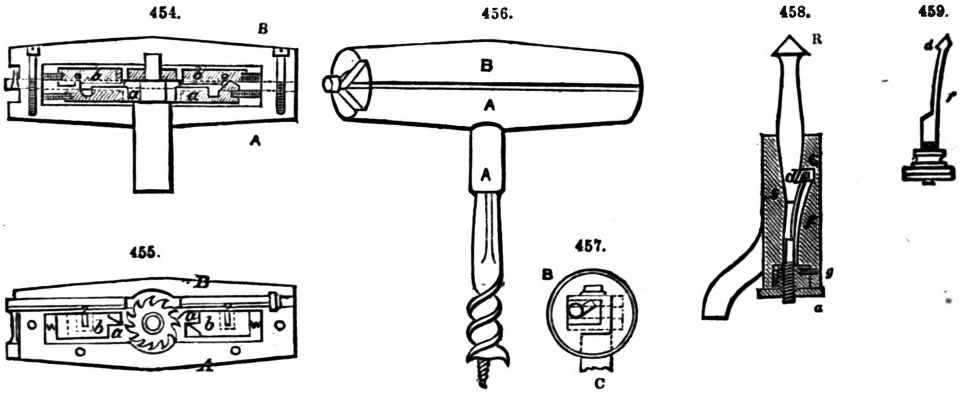
The ship-auger, shown in Figs. 446, 447, has the cutting portion B of the auger attached to the screw portion by means of a *dove-tail notch*, formed by the shoulder *b*, inclined end *d*, dowel *f*, and screw *e*. This method of construction was invented by J. W. Hoagland.

The expanding auger-bit of L. H. Gibbs is shown in Figs. 448, 449, 450, 451. In this instrument the plate B is received into the slot D in the auger A; and by inserting the lower pin *g* into one of the series of holes in the plate B, the cutting-lip *j* on the plate B can be set further out or in, so as to bore larger or smaller holes. This invention consists of the adjustable plate B, with the rib *d*, lip *j*, index holes *c*, *c*, *c*, *c*, in B, combined with the auger A, with slot D, tapering-pins *g*, *g*, and *set-screw h*, as shown in the figures.




Figs. 452, 453, illustrate C. W. Cotton's method of securing augers to handles by having a metallic tube B placed around the centre of the handle, a transverse rectangular taper-hole *a*, made through the handle and tube, and a metallic band C, placed around the tube B, and turning loosely on it; the band C having slots *c d*, made through it, a part of the slot *d* being taper; then, the shank of the auger being placed in the hole *a*, and through the slots *c d* in the band, the shank is secured to the handle by turning the band, which causes the edges of the taper portion of the slot *d* to pass into the notches *f*, *f*, of the shank.

Figs. 454, 455, 456, 457, represent a *gimlet* or auger handle, invented by G. H. Talbot. This inventor does not claim the method of giving a revolving action, in either direction, to the boring-




tool by reversible pawls and ratchets, as such arrangement is common to *drill-stocks*. His invention consists in forming gimlet or auger handles so internally arranged, that when the pressure of the hand is applied on both sides of the axial line of the bit, and under the usual clutch of the hand over the centre line, the accompanying devices present no obstruction, but are protected from injury or derangement, as shown in Figs. 456, 457.

A mode of securing brace-bits in their sockets, proposed by E. W. Nichols, is shown in Figs. 458, 459. The bit R is represented as being fastened to the stock S. To loosen the bit, the nut *a* is turned, thus screwing down the shank of the spring, until the projection B of the spring springs back into the recess *c*, in the stock, when the bit may be drawn out. The pin *g* enters a groove in the outside of the nut *a*, which serves to confine *a* to the end of the stock.

Fig. 460 shows a ground-auger, invented by David Ring. It consists of two semicircular discs, D and E, of steel, each furnished at the ends of its straight-edge with cutters R and *j*, one pointing upwards, the other downwards. The cutter can be expanded by means of slots *f* in the discs, through which the confining-screws are passed into the cutter-heads at the bottom of the shaft: the latter is furnished with a gimlet-point, to facilitate its entrance into the earth.

Fig. 461 represents a hollow auger, invented by Wychoff. The cutters A A are each only half the width of the kerf, and are provided with two or more projecting cutting-points C and D, so arranged as to cut in parallel but concentric planes.

Another hollow auger, invented by J. McClure, is shown in Fig. 463. In this the cutters can be adjusted to different sizes of tenons by means of inclined cutter-bearing pieces, sliding upon inclined supporting-pieces *f f*. It is used in combination with a receding centre *b*.

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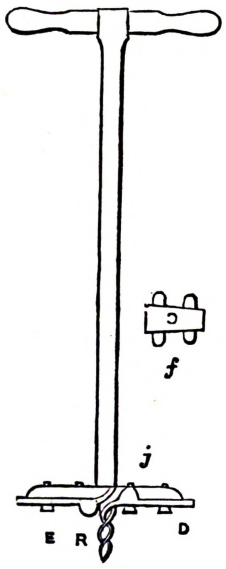


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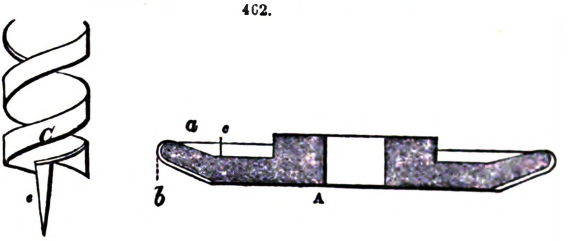


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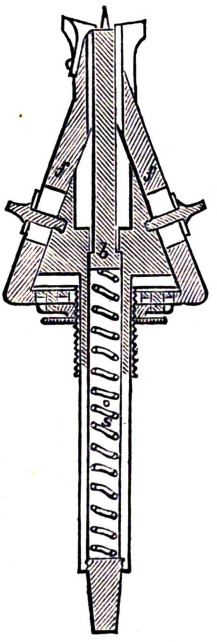

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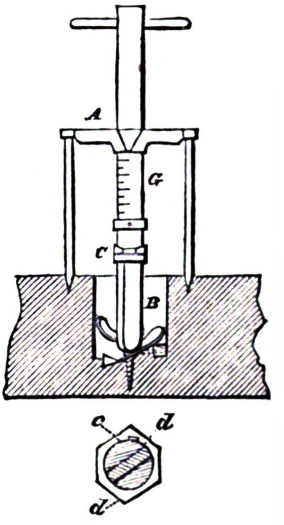


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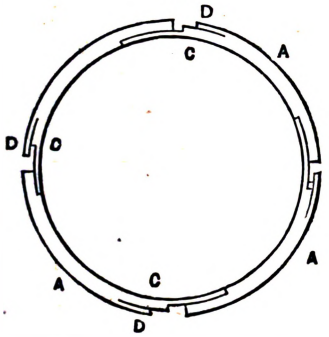



Fig. 462 shows a tool for finishing augers, invented by R. Jennings. It consists of a wheel or burr, having a bevelled surface *a* on one side, and a semicircular edge, corrugated to form a series of cutters *b*, which have a radial or nearly radial position, and extend from the inner edge of *a* to the outer edge of the same. These cutters are placed entirely around the semicircular periphery of the wheel, and act in combination with the concave surface *c* at the opposite side of the wheel.

Fig. 464 represents an auger invented by H. T. Love. This differs from common augers, in having the cutting floor-lips semicircloid in form on their cutting-edges, these edges forming an obtuse angle with the axis of the auger.

The auger invented by E. C. Gillett consists of a cam-sleeve C, Fig. 465, in combination with a slotted shaft G and the flat, notched shank *d* of an auger B. It is so arranged, that the shank of the auger will slide into the long slot in the shaft, through the cam-sleeve, which is then turned till it catches into the notches in the flat shank of the auger, and holds it fast in the shaft.

*Hardening Steel-cutting Tools.*—Any substance which combines chemically with iron will impart hardness to it; but the presence of carbon is required in order to produce that peculiarity, softness after tempering, which we observe in so high a degree in steel. Other substances, which have sufficient cohesion, produce a similar, but weaker, effect on iron than carbon; such are sulphur, or arsenic, and perhaps others: but no other substance is more available and more perfectly suited for this purpose than carbon. When the difference between hardened and tempered steel is caused by carbon or any other substance, in chemical union in the hardened, and in mechanical

admixture in tempered steel, it is evident that this condition must be dependent upon temperature or other agencies. German steel manufactured at a high heat requires a white heat for hardening, and its carbon is so firmly united to the iron that this kind of steel may be welded to it with great facility. Refined shear steel, which has been much heated and hammered, will bear, next to German steel, the highest heat in hardening and welding. Ordinary cast steel will bear less than shear steel, and is welded with difficulty; the finest cast steel will bear the least degree of it, and cannot be welded to iron by the common process. This shows that a large quantity of foreign substances cause the steel to be more fusible, and to bear less heat in hardening. The degree of heat by which the chemical union of carbon and iron is accomplished is, therefore, not permanent; it varies with the fusibility of the metal. This we observe as well in cast iron as in all other metallic alloys. The change in the constitution of steel may be produced at very low temperatures, indeed at almost any temperature. The finest edge and a high degree of hardness are produced by the mere hammering of steel; and, if the above theory of the constitution of hardened and tempered steel is correct, the mechanical mixture of carbon and iron in tempered steel is converted into a chemical compound by mere compression. We recognize this fact in drawing wire, sheet iron, or in hammering iron, or any other metal or alloy. In these operations a large quantity of heat is liberated by compression, which may in some measure account for the metamorphosis; but we find that when the compression is very rapid, and brought about by great force, the phenomenon attending its application is similar to that of a strong heat, —the metal becomes extremely brittle. The best edge, and consequently the highest degree of cohesion and compactness in steel, is produced by striking a small bar of tempered steel with a small steel hammer, on a cold polished steel anvil, so as to avoid any considerable or perceptible increase of heat. If this operation is performed on a square bar of steel, by means of a hammer of the smallest size, of one or two ounces weight, and the corner of the steel thus compressed is ground down so as to remove the surface which has been touched by the hammer, we obtain an edge which cannot be surpassed for fineness by any other means of hardening. This shows that hardening may be performed by a variety of means, and that heat is not absolutely necessary. The strong cohesion of the metal is the cause of this phenomenon; and by whatever means we produce the close contact of the particles of metal and carbon, we secure hardness. These reflections serve to explain the manipulations which are employed in the manufacture of steel.

The common means by which steel is hardened are well known; these form no part of our investigations; but we may remark here that it is not so much the degree of heat to which steel is exposed before *chilling* it, as the difference of temperature between the cooling medium and the heat of the metal, together with the heat-conducting capacity of the *refrigerator*. Experiments have shown that little is gained by substituting other fluids than pure water for hardening steel. This is an entirely practical operation: the temperature of water may be in all instances the same, and fresh common spring water, or river water, is as good as any other fluid. But as the liability of steel to lose some of its component parts increases with the heat to which it is exposed, and as, near its smelting point, it assumes the nature of cast iron, it is found necessary, in order to preserve its original character, to perform the hardening operation at the lowest possible heat; for these reasons, water as cold as possible is used; and as, by plunging the hot metal into it, an atmosphere of steam is formed around it, which is a bad conductor of heat, either the metal or the water ought to be moved, to expose the hot metal to renewed action of the cold particles. The application of acids or salts for hardening is injurious to steel, however good conductors of heat such solutions are. Some of the fluid will always penetrate the metal and cause its decomposition. The use of oil or fat for this purpose is, if not equally prejudicial, at least of little benefit. That fluids penetrate metals, and particularly iron, is shown in wire factories: when iron wire is cleaned, after annealing, in diluted sulphuric acid, which is, by neutralization and washing, as far removed as practicable, it retains always some of the acid, which causes the wire to be brittle when fresh. An exposure of the wire to the atmosphere for some time removes the acid, and therefore the cause of brittleness. Wire thus cleaned by acids is often permanently injured in its strength, which does not happen with wire which is cleaned by the old method, with sand and water.

*Annealing Steel for Cutting-tools.*—It has been recommended, and it is also practicable in some instances, to modify the heat of the metal and the cooling medium for hardening, so that the contact of the two produces the required degree of hardness. A uniform degree of heat cannot be applied to all kinds of steel; and since the mode and time of heating is also important, and the fluid refrigerator cannot be uniform in composition and temperature, it is easily understood that this method of hardening cannot be universal. The common mode, and perhaps the best one for hardening, is to expose the steel to such a degree of heat, and so to cool it in water, that it assumes the highest degree of hardness, and then temper by exposure to a moderate heat.

A variety of means have been proposed for tempering hardened steel, such as melted fusible metals, lead and alloys of lead, heated fat or oil. When we reflect on the nature of steel, we soon find that the various kinds require different degrees of heat, by which they assume a definite texture or hardness, and that neither a certain degree of heat nor a certain colour of its tempered surface will indicate the actual condition of the steel. The operations on steel are of so delicate a nature that they cannot be brought under general rules—they are entirely dependent on the skill of the practical man; no language can impart that information which is applicable in all cases. The following statements are for these reasons to be considered as relatively true, and not as generally applicable.

Steel which has been hardened to the extreme should be exposed to a heat of 400° for chirurgical instruments, such as lancets—it assumes then a faint yellow colour on its polished surface; to 425° for razors, which tempers it yellow; to 432° for penknives, which it also tempers yellow; to 468° for scissors and cold chisels—the colour is brown-yellow; to 490° for edge-tools and common cutlery—colour purple; to 508° for table-knives—colour also purple; to 530° for small springs and weapons, to 537° for large springs, saws, *augers*—the colour is blue; to 580° for large

saws, the colour of which it tempers to dark blue; beyond 600° steel becomes black, is annealed and soft. Steel which requires a high degree of heat for hardening, demands also more heat for tempering than that which hardens at a lower degree of heat; and steel exposed to a tempering heat of a certain degree for a length of time, increases in softness, even when the intensity of heat is not increased.

The colour of steel in the fresh fracture is white, like deadened silver. When tempered, it becomes more grey; and when annealed, it is grey, but the intensity depends on the kind of steel or amount of carbon. In all cases, the hardened, as well as the annealed steel, should not exhibit to the eye, even when aided by a lens, any crystallization. Hardened steel shows a little higher lustre than annealed steel. In making these distinctions, we should always regard hammering as equal to hardening by heat and refrigeration.

Steel is not very ductile. When cold, it will not bear much alteration of form, and when heated, it is, in some kinds, equal to iron. Cast steel will not bear much bending. German steel, shear steel, and all kinds of hammered steel, are more ductile when hot than those kinds which have been less subjected to compression.

The degrees of heat at which steel melts vary considerably: German steel requires the highest heat for melting—this may be about 3600°; the best kinds of cast steel will melt at considerably less, or about 2800°.

Oxygen has little effect on hardened steel; still, white cast iron, with much carbon, is superior to steel in resisting oxidation. The pure white colour of hardened steel, and its susceptibility of being oxidized when heated, cause the beautiful colours of tempered steel. When heated under a cover of oil, these colours do not appear; or, when such coloured and heated steel is brought into an atmosphere of hydrogen, the colour also disappears. This shows that colour is caused by oxidation, and that, in tempering steel under a coating of oil, extreme caution is required to hit the proper point of heat. These colours proceed from a coating of oxide, which, in its extreme thinness, causes the yellow, and when thick, blue; and finally, it becomes opaque and black. Acids facilitate the formation of these colours; alkalies delay or prevent them altogether. Pure iron requires a higher heat, to show the same colour, than steel: the best steel, and also white cast iron, show the series of colours at comparatively the lowest degree of heat. These tests may be arranged in the following order:—

| | |
|---|---|
| Very faint yellow, for lancets | temp. from 400° to 430° Fah. |
| Pale straw yellow, for razors and scalpels | „ 430° to 450° „ |
| Full yellow, for penknives and chisels | „ 470° to 480° „ |
| „ for cast iron | 470° „ |
| Brown, for scissors and chisels | temp. about 490° „ |
| „ for wrought iron | 495° „ |
| Red, for carpenters' tools in general | temp. 510° to 520° „ |
| Purple, for fine watch-springs and table-knives | temp. about 530° „ |
| Bright blue, for swords and lock-springs | „ 550° „ |
| Full blue, for daggers, fine saws, and needles | temp. 560° „ |
| Dark blue, for common saws | temp. about 600° „ |

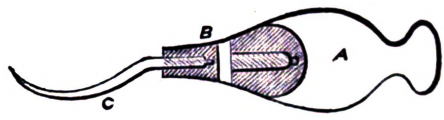
See HAND-TOOLS.

AWL. FR., *Alène;* GER., *Ahle, Pfrieme;* ITAL., *Lesina;* SPAN., *Lesna.*

An awl is a pointed instrument for piercing small holes, as in leather or wood. The blade is differently shaped and differently pointed for different uses, as in the brad-awl, saddler's-awl, shoemaker's-awl, and so on.

Fig. 466 shows the method of fastening an awl into the haft, invented by R. Egan. A metal socket-piece B forms the end of the haft A, to which it is attached by means of a stout tongue screwed into the haft. This socket has an internal screw, which is formed to receive the threaded shank of the awl C.

466.




AXE. FR., *Hache;* GER., *Axt;* ITAL., *Accetta, Scure;* SPAN., *Hacha.*

An axe is an instrument, usually of iron, with a steel edge or blade, for hewing and chopping wood. See HAND-TOOLS.

AXIS. FR., *Axe;* GER., *Achse;* ITAL., *Asse.*

The straight line, real or imaginary, passing through a body, on which it revolves, or may be supposed to revolve, is termed an axis. See MECHANICAL POWERS.

AXLE-GREASE. FR., *Graisse d'essieu;* GER., *Lagerschmiere;* ITAL., *Untume;* SPAN., *Grasa, ó gordura para eje.*

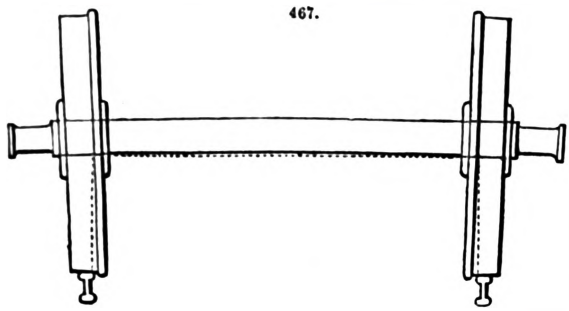
See ANTIFRICTION METAL. FRICTION.

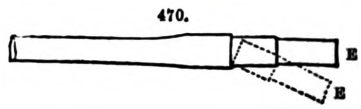
AXLES. FR., *Essieu;* GER., *Welle;* ITAL., *Sala;* SPAN., *Eje.*

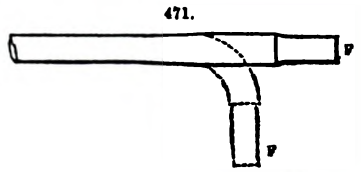
An axle or axle-tree is a transverse bar or shaft, connecting the *naves* of the opposite wheels of a car or carriage. Railway axles are termed *leading* and *tracing*, from their position in the front or in the rear of a car or truck, respectively. The journal-box of an axle is called an *axle-box.*

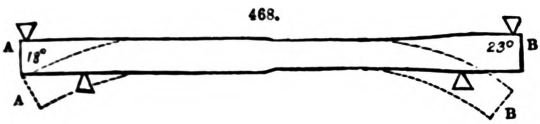
Thomas Thorneycroft, in a paper read before the Institute of Mechanical Engineers, considers an axle as having certain relations to a girder in principle. Girders generally have their two ends resting on two points of support, and the load is either located at fixed distances from the props, or dispersed over the whole surface: just so with the axle; it has its points of support and its loaded parts; but it is not clearly evident which are the loaded parts and which the props. It is found that the inclined surface of the wheel-tire ranges from 1 in 12 to 1 in 20, and, consequently, the direct tendency of the wheels under a load is to descend that incline, so that every vertical blow which the wheels may receive is compounded of two forces, namely, the one to crush

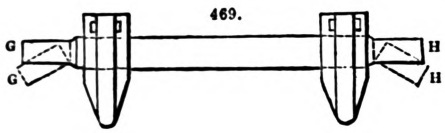
the wheels in the direction of their vertical plane, and the other to move the lower parts of the wheels together: it will be seen that these two forces have a direct tendency to bend the axle somewhere between the wheels; should that yielding, or bending, extend no farther than one-half the elastic limit, if long continued, fracture will ultimately take place; but should the elastic limit be exceeded, the axle takes a permanent bend, the wheels are then diverted from their vertical plane, and, as a matter of course, leave the rails. To demonstrate this, an axle reduced in the middle to 3¾ in. diameter was placed upon two props 4 ft. 9 in. apart, and loaded in the middle: the utmost of its deflection, without a permanent set, was ·232 in., the load carried 7 tons. An axle reduced to 4 in. in the middle was then placed upon the props 4 ft. 9 in. apart: its utmost deflection, without a permanent set, was ·281 in., the load carried 9 tons. Another axle, but parallel, 4 15/16 in. diameter, was next placed upon the props 4 ft. 9 in. apart: its utmost deflection, without a permanent set, was ·343 in., the load carried 14 tons. Hence, by reducing an axle of 4 15/16 in. diameter in the middle to 3¾ in., its limit of elasticity is reduced from ·343 in. to ·232 in., and the load required to produce that elasticity is from 14 to 7 tons. Fig. 467 shows the position of the wheels to the rails when the bending of the axle has exceeded its elastic limit.

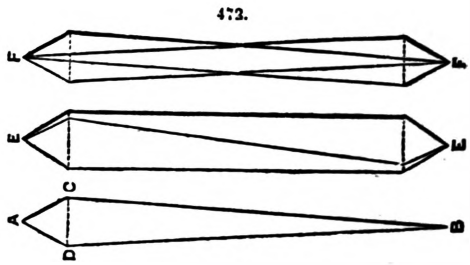



To ascertain what influence the reduction of an axle in the middle would have on its strength to resist sudden impact, compared to an unreduced one, an axle was made as represented by Fig. 468, which shows the end A parallel to the centre 4½ in. diameter, and the end B drawn down from the back of the wheel towards the centre, where it is 4 in. diameter. The end A was subjected to impact—the relative position of prop and ram was the back of the wheel and the neck of the journal; this end received forty-six blows of the ram, and bent to an angle of 18°. The end B was then subjected to impact—the prop and ram in the same relative position, when it bent back to an angle of 23° with only sixteen blows of the ram, as shown by the dotted lines in Fig. 468. To ascertain what influence a shoulder behind the wheel would have on the strength of the axle at that part compared to one without a shoulder, an axle was cut in two, Figs. 470, 471, the end E turned from the neck of the journal, leaving a shoulder ⅛th in. deep as a stop to the wheel; and the end F turned from the neck of the journal to the same diameter, but no shoulder left. The end E was subjected to hydraulic pressure, the load being in a direct line with the shoulder, when it broke in two with a load of 60 tons. The end F was subjected in the same way to hydraulic pressure, when it bent into the form shown by the dotted lines with 84 tons. To ascertain what influence the position of the wheel in relation to the neck of the journal would have on the strength of the latter under impact, a piece of an axle, Fig. 469, was prepared, with a journal taken down at each end, the end G keyed into a cast-iron frame, and the face of the frame in a line with the neck of the journal; the journal was then subjected to the impact of a ram falling 10 ft., when it broke off at the seventh blow. The end H was keyed into the cast-iron frame in the same way, but with the neck of the journal projecting 1½ in. from the face of the frame; the journal was then subjected to the impact of the same ram falling 10 ft., when it broke at the twenty-fourth blow.

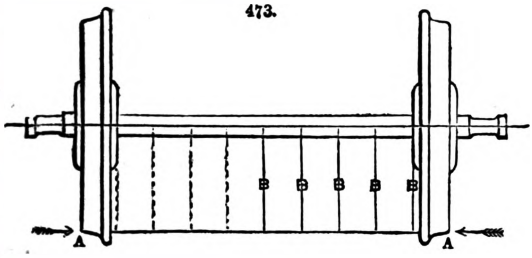
From these experiments, and from the acknowledged deteriorating influence of vibration or bending on iron, especially when continued any great length of time, it is Thorneycroft's opinion that neither shafts nor railway-axles ought to be reduced in the middle, but rather, if there is to be a departure from the parallel form, they should be made thickest in the middle, and thus effectually prevent any vibration or bending whatever.

In the discussion which followed upon Thorneycroft's paper, E. A. Cowper said that Thorneycroft's conclusions were arrived at by experiment, unaided by theory. If A B, Fig. 472, is taken as the axis of a railway-axle, A and B as the centres of the journals, and C as the centre of one

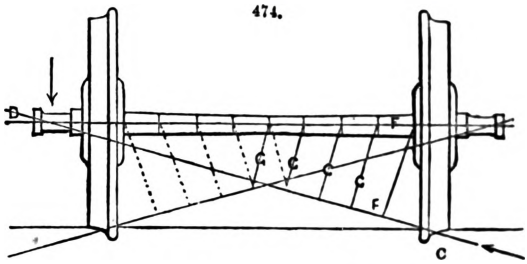
wheel, we should have the case of a girder weighted at A and B, and supported at C; the proportionate *strength* ought, therefore, to be as a triangle A C D, and a triangle B C D. Now if we put two of these triangles together, as at E E, we shall at once arrive at the result that the strength of the axle should be uniform between the wheels, and consequently parallel, and from the wheels to the journals the strength should be as a triangle; and if we had merely to do with a strain due to the weight on the journals of the axle, these proportionate strengths would be strictly correct. *But* we have to provide against the lateral strains, from the flanges of the wheels suddenly striking the switches and crossings in passing through them; and this is so much greater than the mere weight on the axle, that it must be considered chiefly in determining the form of an axle; if, therefore, the Fig. A C B D were reversed on itself, the outline thus given would represent the proportionate *strength* of an axle, as at F F, which is fully in accordance with the usual tapered form of axles. *The actual diameters* can be easily arrived at, by taking the cube root of the width.

J. Ramsbottom, in the same discussion, considered that whether in the case of axles or machinery of any kind, there must be an error in the proportions if any one could say beforehand at what point a fracture was likely to occur. He could only conceive one instance in railway practice where axles should be parallel, and that was in the case where the forces were applied in a line directly parallel to the axle; as at A A, Fig. 473. If a pair of wheels are running, for

473.




474.




instance, between rails converging to a point, the axle should be parallel, since the effect of the leverage is the same at all points B B between the wheels. But there is another and more important force resulting from a lateral blow upon one wheel only, coupled with the load of the vehicle on the axle, the direction of which will be tolerably well indicated by a line C D, Fig. 474, drawn from the circumference of the wheel on one side to the centre of the journal on the other side; and if the line F F is drawn perpendicular to this, from the axle close to the wheel, it will represent the greatest effective leverage, tending to break or strain the axle at that point; and the strain upon any other point of the axle may be found by drawing lines G G parallel to this; in fact, the cube roots of these lines will give the diameter of the axle at the points where they fall.

To obtain the advantage of the shoulder at the inner side of the boss without weakening the axle, A. Slate has suggested the introduction of a small shoulder inside the boss of the wheel near the outer side, see A, Fig. 475. The wheel has to be bored out a tight fit, and forced on to the axle by a hydraulic press, but the first, 1½ in. from the inner side, must be slightly coned, as shown at B, so as to remove the grip on the axle from the extreme edge of the boss, and prevent the tendency of the axle to break at that point.

475.

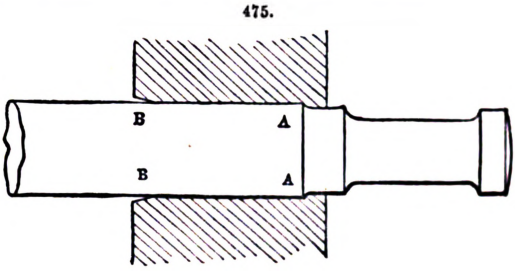



Fig. 476 is a longitudinal section, and Fig. 477 a transverse section, of the axle-boxes employed on the North-Kent line. The top of the box is circular, for a peculiar arrangement of springs; the box is cast open-fronted, with a movable front A to attach by screws, a grease-tight joint being maintained by an elastic substance between. From this arrangement the interior of the box can be inspected, and a new brass applied, without lifting the carriage. The back of the box round the axle is cast with a round-edged projecting lip B B. A plate of metal C C, with centre hole fitting the axle, is secured by bolts to the back of the box, with a piece of leather D D, the orifice of which is enlarged into a partial pipe-form round the axle, to give increased bearing-surface. This leather presses equally on the axle and on the lip of the box, and thus a tight joint is maintained, which preserves the grease without overflowing above the level of the bottom of the axle. The bolt-holes in the metal plate are vertical and oblong, so that when the upper bearing-brass wears, and causes a corresponding wear in the plate and leather, and consequent leak below, the two latter may be drawn upwards to fit the lower part of the axle. At the top of the box there is a screw-tap E, for feeding, with holes through it to admit the ingress and egress of air. This tap serves to feed an upper chamber F, with holes to the axle as usual; this tap also feeds the lower chamber G, which, in addition, catches the grease that falls through from the upper chamber by the working of the axle. A piece of hard wood H is applied between the end of the axle and the front of the box, to prevent wear of the shoulder-collar of the bearing-brass. Two collars of light wood I, I, float on the oil or grease in contact with the lower side of the axle, and thus carry up the lubricating material, if it happens to be below the level of the axle. Figs. 478, 479 are a longitudinal section and back view, showing an upper and lower feed of an axle and axle-box. To retain the oil or grease, a conical metal spring C C is inserted in a corresponding circular groove at the back of the box; by its elastic expansion it presses against

a strip of leather lining the groove, and thus forms a tight joint. The small end of the conical spring clips a leather pipe-collar D D, fitted on the axle, which collar may either revolve with the axle in the small end of the spring, or it may be fixed to the spring, and the axle revolve within

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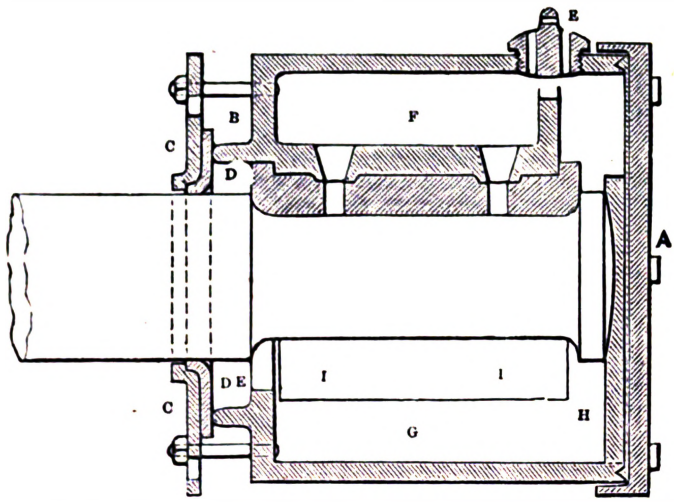


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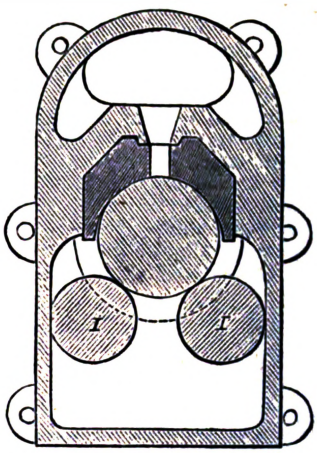
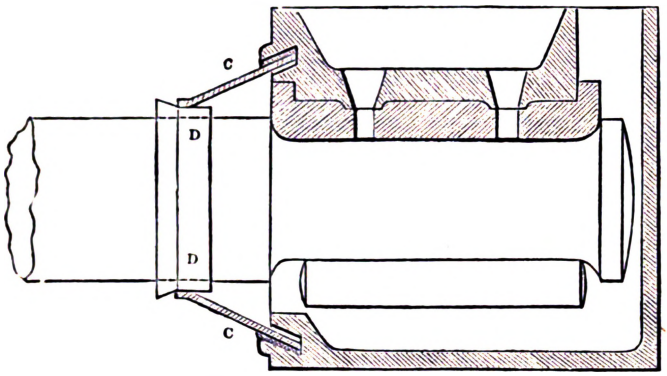



the leather collar; as the spring expands against the groove in the box, it has no tendency to press the axle or leather too tightly, so as to cause much friction. The conical spring is prevented from

478.

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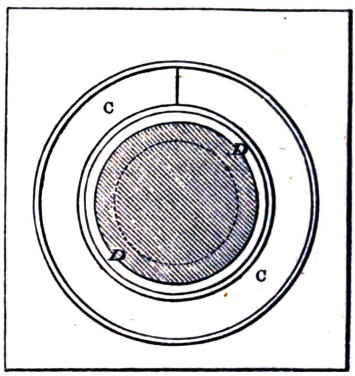
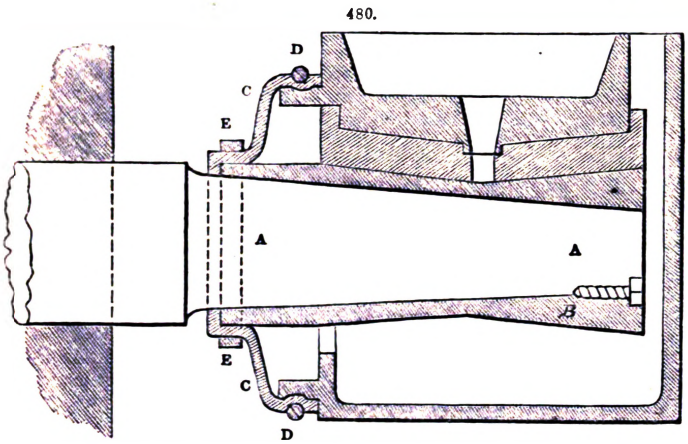
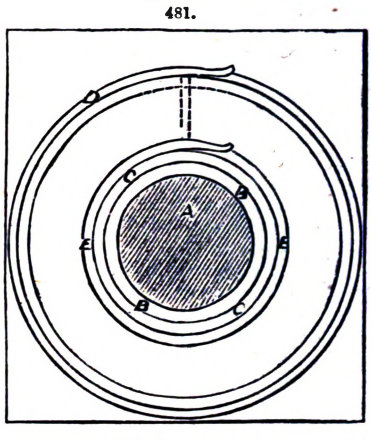



turning, by a stud; the edges of the spring overlap each other, to keep out dirt, and the hollow space between the spring and the axle may be filled with sponge or cotton-waste. Figs. 480, 481,

480.



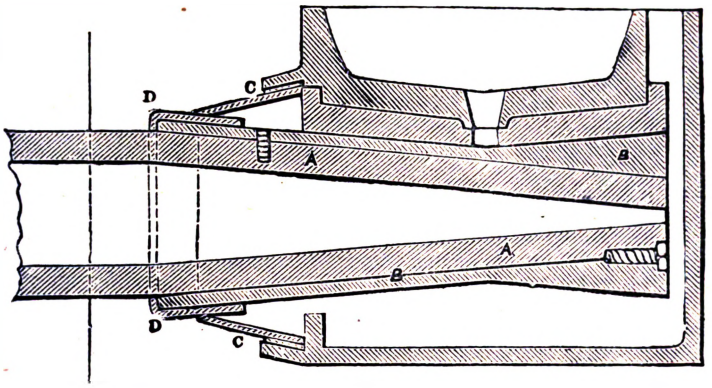

481.




show a longitudinal section and back view of an axle-box on a similar arrangement, in which a conical pipe of blocked leather C C, is secured to the box-lip by an elastic ring D D, similar to a key-ring, and clipped to the axle by a second ring E E. Both the spring cone and leather cone

will, by their free action, accommodate any irregular movement of the box, and prevent loose wear between the metal plate and leather. In all cases where any material comes in contact with the revolving axle, it is essential that the surface be properly smoothed, that the pressure be as light as may be convenient, and the lubrication certain. Fig. 480, in addition to the axle-box arrangement, shows a mode of applying movable journals to axle-arms, either new or old. Thus the journals A A, may be forged down to a taper, with the object of extending the distance of the bearing from the wheel, or of increasing the diameter of the axle-bearing. The movable bearing B B, may be of wrought iron or of cast iron, well got up and *case-hardened;* and manufacturers might be enabled to supply cheaply a superior class of axle-boxes and axle-bearings. This arrangement could be well adapted to the hollow axle shown in Figs. 482, 483, and it also enables

482.

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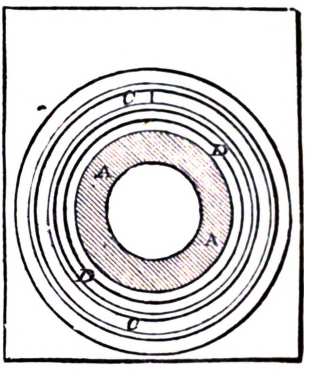



constructors, at comparatively small cost, to replace axles, when rendered unsafe by long running and much vibrating.

It should be remarked that it is desirable in all cases to get the axle-bearings as long as is convenient, even when not required for bearing-surface, for the following reasons:—The points of the springs which support the frames are at a considerable elevation above the axle-bearing, and act with mischievous leverage to tilt the axle-boxes laterally to the carriage, when the wheel-flanges strike the rail. It is evident that unless there be some proportion in the length of bearing to the height of the spring, there will be a great strain upon the guards of the axle-boxes to keep them steady.

The axle-box described above is the first application of the principle of retaining the grease or oil, by closing in the back of the box.

Many similar contrivances have since been brought out by various other persons for the purpose of retaining the grease in the axle-boxes, but it appears that the original application of the principle was due to W. B. Adams, in May, 1847. (See 'Proceedings of the Institution of Mechanical Engineers,' April 27, 1853.) There does not appear to be very material variation in any of the subsequent plans.

As to the practical mechanism for keeping out dirt and preserving the bath of grease, it must vary with circumstances. Many axle-boxes are so close to the wheel-bosses, that the leather pipe-collar is the only practical arrangement; and having come into general use, it is difficult to change it; but W. B. Adams prefers the elastic metal collars, C C, shown in Figs. 478 and 482, pressing upon leather pipe-collars D D.

The object sought is to form a tight joint between the box and the axle, which are both exposed to rough jolts and a tilting movement of the box on the axle; therefore the medium to from the joint should be flexible, and not liable to be put out of order.

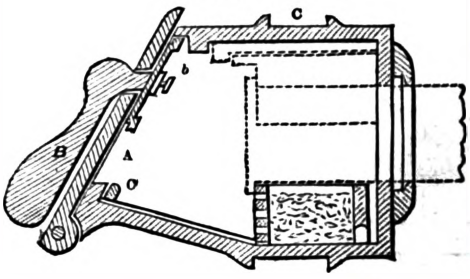
The mode of lubrication from above the bearing has one objection, in the liability to accident by dirt getting on the arm, and from the holes wasting a most important part of the bearing-surface; but W. B. Adams thinks it preferable to retain this arrangement, keeping the holes small, as it renders a security in case of any accident happening to the lower reservoir.

Two forms of journal are shown in the diagrams; one the double cone, Figs. 480 and 482; the other the ordinary cylindrical journal with collars, Figs. 476 and 478. There is an advantage in the double cone with the small diameter in the centre of the bearing, that it has a tendency to cause the lubricating fluid to press outwards from the centre while in rapid motion. The cylindrical bearing between collars has also this disadvantage, that the box is not kept in its position by gravity, but by a very small collar-surface, which, being vertical, does not retain the lubricating fluid so easily as the horizontal surface; and, moreover, by its larger diameter has a tendency to throw it off by centrifugal action. Where the boxes fit tightly to the guards, the collar-bearings are frequently subject to rapid wear; and lateral thrust is more destructive than the downward pressure of the load. The small rounded corners next the collars, intended to prevent the "nicking" or breaking of the axle, are of little service to give the box a centripetal tendency. The cylindrical bearing has the advantage, that the bearing-surface is not lessened by end play; and with the axle working in a bath of lubricating material, the collars will at all times be safe. In either case, of the cone or the cylinder, it is clear that the lubricating bath below will be the safest precaution against heating. As regards the strength of the axle, the coned journal has the advantage by its gradual tapering form, supposing an equal amount of metal in both cases. The fitting of the bearing-brass to the journal is a matter of greater nicety with the cone than with the cylinder. With cylindrical journals the usual practice is, to make the bearing-brass of con-

siderably larger radius than the journal, so that it bears on a very small surface, which wears to a polish, and gradually extends to the half diameter. In point of fact, railway bearings are made to grind themselves to a true fit or work, instead of being accurately ground and fitted beforehand, as is the case with nicer machinery.

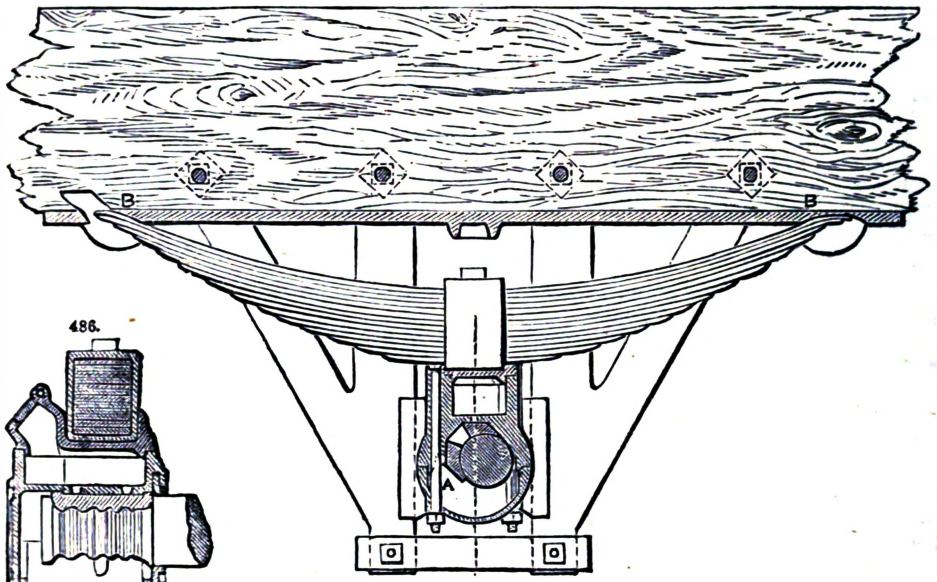
In the axle-box, Fig. 484, the lid vibrates on a hinge, and is secured above by a disc on the axis of the handle, engaging a recess on the upper edge of the box. The floor of the oil-chamber is inclined upwards and outwards, and has a loose perforated frame to hold the packing. In this arrangement of J. Montgomery, shown in the figure, the lid A of the journal-box C, is hinged below and secured by a handle B and jamming-cam *b*; C' is the loose or hinged rack frame, placed inside the axle-box C.

484.




W. G. Craig, of Manchester, in a paper published in the 'Proceedings of the Institution of Mechanical Engineers,' observes that in axle-boxes the principal defect is in the seats for the gun-metal bearings. These are arranged in various ways, but all involving expensive fitting of the bearings into their places to secure them from getting loose, notwithstanding which they frequently turn on one side, as represented at A, in Fig. 485, and are also liable to drop out of their places entirely and remain in the bottom of the axle-box, causing the journal to come in contact with the cast-iron box, which is soon destroyed, as in the example shown in Fig. 486,

485.

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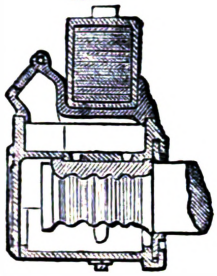


which is one out of a large number of similar cases. In many instances the journals are completely twisted off. These occurrences necessarily cause great delays to trains, and require the carriage or wagon to be sent into the workshops for repair. In order to prevent the brasses from coming out of their places, they are cast with deep sides, and not unfrequently riveted to the axle-boxes; but the consequence of this is, that when the brass warms, its sides grip the journal, and soon cause the bearing to heat.

Another defect in axle-boxes is in the mode of lubricating, which tends to create the evil of hot journals before the remedy can act. This arises from the thickness of the metal that forms the seat of the bearing and bottom of the grease-chamber, which in many cases amounts, together with the bearing, to two inches thickness above the journal, and must be heated through by friction before the grease can be brought down to lubricate the bearing. In numerous instances, from the metal becoming overheated, the grease is rendered fluid, and runs out and is wasted.

Another disadvantage is that, from the carelessness of workmen, the holes for the passage of the grease through the axle-box and bearing are often not made to correspond, and the flow of grease to the journal is consequently obstructed. It is also difficult to clean out such holes when required, to do which properly involves a considerable loss of time, and the evil arising from not frequently picking them out is a total stoppage of the lubricating material, causing cut journals.

Another difficulty is that of getting the grease to the back of the grease-chamber to lubricate the inner collar. This is now done by the greaser pressing back the grease with his knife, when time admits, and is generally only imperfectly accomplished whilst the carriages are temporarily stopped at a station.

Further, the number of parts belonging to the axle-boxes now in general use, bolts, nuts, leather packing, and so on, all involve expensive fitting, and are subject to frequent displacement.

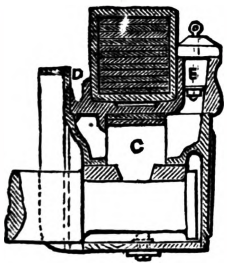
In the axle-box grease-covers, again, there is a constant rattling noise with all iron covers that are without springs, and they often require repair from being made slight, and the hinges being strained; and with the sliding arrangement, the covers get lost in transit, and grit and other foreign matter then mix with the grease, and produce hot axles, either by stopping up the lubricating holes, or by coming in contact with the journal. An objection also to iron covers is, that during the summer months they quickly conduct the sun's heat to the grease and cause it to run to waste.

In the spring fittings, W. G. Craig states that all arrangements are defective where bolts, nuts, or screwed spring-clips are used for fixing the spring to the axle-box, as these are not found sufficient to retain the spring in position in ordinary concussions, entailing the frequent loss of bolts and nuts, and at times of the whole spring. It is also objectionable for the ends of the spring to bear against fixed shoes fastened to the sole-bars, since the spring, on elongating, causes the ends to rub hard upon the shoe, which wears a recess in it, and also wears the top plate of the spring; the result is that a shoulder is formed upon the shoe, and in many instances the spring cuts the body of the shoe entirely away and bears upon the wood, as represented at B B, Fig. 485, which is an exact copy of one of the many so found on the Manchester, Sheffield, and Lincolnshire Railway, in all such cases the spring is prevented from acting beyond the limit of the shoulder formed on the shoe. Amongst the methods adopted to remedy this defect, the spring ends have been softened and bent downwards to fit the shoe, and the top plate of the spring has been thickened to allow for wear; the former plan has been abandoned as inefficient, and the latter, which is now generally in use, is subject to the objection before named.

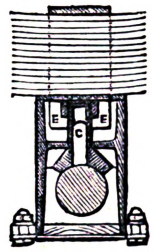
The failures of the axle-boxes, bearings, grease-covers, and spring fittings described above, involve a serious item in the working expenses; and from his experience of the causes producing those failures, W. G. Craig was led to adopt the construction of axle-box and spring fittings, which we shall now describe.

The improved axle-box is cast in one piece to avoid all expensive fitting of leather packing, bolts, nuts, and so on; the mode of lubricating through the axle-box seat by means of holes is dispensed with, and the lubrication is effected direct through the gun-metal bearing. All expensive fitting of the bearing is avoided by casting an oblong hole in the axle-box seat, to receive a projection C, Figs. 487 and 488, cast upon the top of the bearing; these can then be put

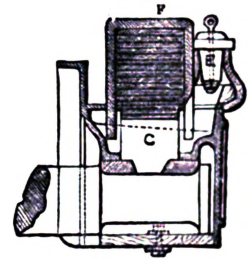
487.




488.




489.




together as they come from the foundry, a slight looseness being of little consequence, since the projecting piece completely prevents the possibility of the bearing turning on one side, as at A, Fig. 485. This axle-box is also much lighter than the ordinary construction, and all bolts and nuts are dispensed with, excepting the two bolts that fasten the under-keep.

The projection cast on the top of the bearing is made hollow, and, passing through the oblong hole in the seat of the axle-box into the grease-chamber above, supports either the cap of the axle-box, as in Fig. 487, or the under-side of the spring itself, as in Fig. 488. By this means is ensured not only the impossibility of the brass turning, but also the perfect lubrication of the journal through the large aperture in the projection, which brings the grease in direct communication with it, so that a very small increase of temperature is sufficient to cause its perfect lubrication. In this case the cast iron of the axle-box is never required to get hot in order to soften the grease, that being one of the chief causes of hot journals. A further advantage obtained by the projecting piece on the top of the bearing is, that the brass may be made of a shallow form, so that it will never require its sides to be reduced to prevent them from clipping the journal.

In the grease-covers, W. G. Craig has adopted two plans to suit different forms of springs. In the first, shown in Fig. 487, the cover D clasps the top of the axle-box, and prevents the admission of grit, dust, &c., which cannot be too carefully excluded from the top of the box. It is cast with an oblong recess upon it, extending upwards, which receives the grease above the level of the grease-chamber, and is fitted with a wooden plug or plunger E, secured by a chain to the wagon, in place of the ordinary iron cover or slide; the grease being thus introduced above the level of the grease-chamber ensures the perfect lubrication of the whole bearing, being forced by the pressure of the plunger into the recesses at the back of the brass.

The second modification of improved grease-cover, shown in Figs. 487 and 489, is combined with an improved spring-fixing; a wrought-iron plate is employed, about $\frac{3}{16}$ths in. thick, and of sufficient size to project over the axle-box top about $\frac{1}{2}$ in. all round; an opening is made in the plate to admit the grease, and two other openings to receive the ends of the spring-clip F, to which the plate is secured by a *cotter*. On the top of the plate is fixed a piece of wood, about 1 in. thick,

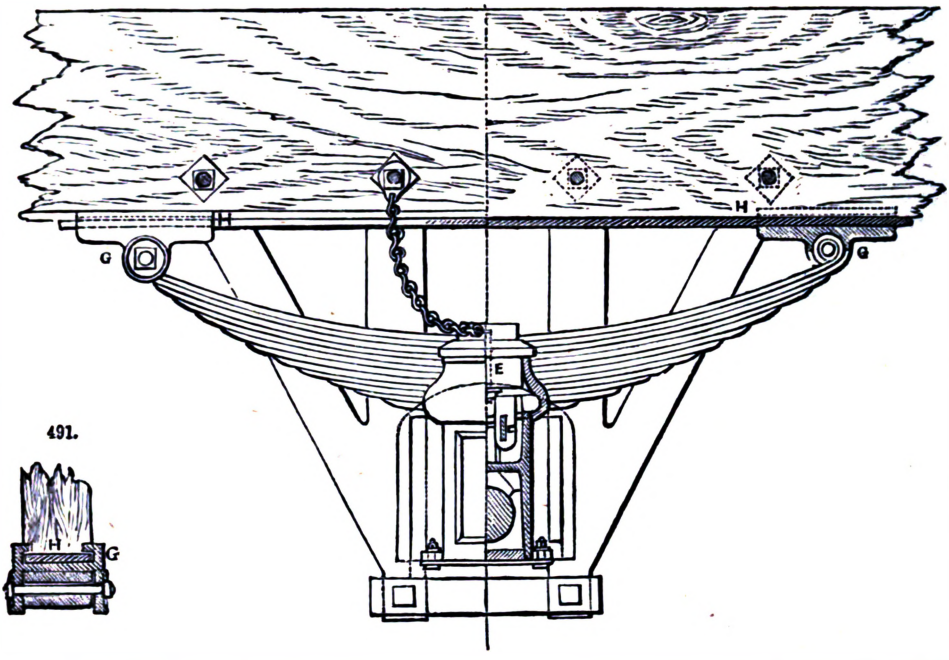
on which is screwed an oblong casting, similar to the oblong recess in Fig. 487, having a wooden plug E to fit the opening: the advantage of this arrangement is, that this portion of the grease-cover can be replaced when broken, without having occasion to lift the wagon.

The improved spring-fixing consists of a simple and cheap contrivance in combination with the axle-box; a piece of iron F, ½ in. thick, and the same width as the spring, is simply bent over the spring to form a clip, Fig. 489, allowing the ends to project to form cotter-holes, and to fit into the cover of the grease-chamber. Two cotters fasten the clip tightly to the spring, and are cut so as to correspond with the length of the grease-chamber, by which means they are prevented from getting loose. The cotters form the two sides of an oblong recess on the under-side of the cover, and receive between them the projecting hollow piece C on the top of the brass, as in Fig. 488. A piece of wood or india-rubber is inserted between the under-side of the spring and the top of the projection C, to form a cushion for the spring.

A modification of the improved spring-fixing, for application to existing stock, is made by fixing two pieces of iron, about 2 in. wide, and the length of the width of the spring, and about ⅜ths in. thick, by means of the bolt through the centre of the spring; on each side of these pieces is fixed a welded hoop of iron, 1 in. by ½ in., as a support for the centre of the spring, in addition to the ordinary small rivet passing through the spring, and a corresponding recess is made on the cast-iron cover of the grease-chamber.

The fittings at the ends of the springs are improved by making the shoes G G, Figs. 490 and 491, to slide on a metal bed H, about ¾ in. thick, and of sufficient length to allow of the play of the spring with the sliding-shoes attached.

490.




491.




The plate H is fixed on the under-side of the sole-bar, materially strengthening the wagon, and the sliding-shoes have grooved sides to secure them to the plate. The spring is connected to the shoe by a bolt passing through the side cheeks of the shoe and the spring-eye, the object being to retain the spring attached to the wagon, when the journals require examination, thus saving considerable expense and time in lifting.

The sliding-shoe maintains the perfect action of the springs, and their working is, in consequence, so easy, as to be almost equal to that of a first-class carriage fitted with scroll-irons, if the same length of spring is used in each.

AXLE-BOX. Fr., *Boîte à graisse;* Ger., *Schmierbüchse;* Ital., *Serbatoio dell'untume;* Span., *Caja dell eje.*

An axle-box is the journal-box of an axle, especially a railway axle. See Axles.

AXLE-TREE. Fr., *Tourillon;* Ger., *Wagenachse,* Ital., *Sala;* Span., *Eje.*

An axle-tree is a fixed transverse bar of wood or iron supporting a carriage, on the rounded ends of which the opposite wheels revolve. See Axles.

BABBIT'S METAL. Fr., *Métal de Babbit;* Ger., *Babbit's Metall;* Ital., *Lega Babbiti.* See Alloys.

BACK. Fr., *Arrière;* Ger., *Rücken;* Ital., *Il dietro;* Span., *Atras.*

*Back.*—Of a hand-rail or rafter, the upper part. Of a stone, the part opposite to the face. When the stone is used as a facing to a brick wall, it is squared at the back; but if the wall is built of *rubble* work the back of the stone is left rough, as it comes from the quarry.

*Back, in Brewing.*—See Sparger.

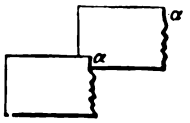
*Back-flap.*—A leaf hinged to a window-shutter, in order that the shutter may fold back to enable it to fit into the side-boxings. Back-flaps, in the best work, are framed in panels, but in

inferior work they are formed of one piece; in either case they are made of less thickness than the shutter, usually an inch when the latter is from 1¼ to 1½ in.

*Back-day* is a term applied to a day, the wages of which are usually kept in arrear. If the workmen are paid on Saturday, their wages are made up to the previous evening. When a workman quits his employment, he is said to take his "back-day," that is, to require his account to be closed.

*Back-hearth.*—The part under the grate, of a stone or an iron hearth to a fireplace.

492.

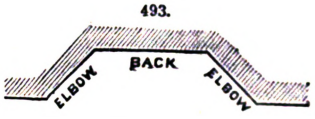



*Back-joint.*—That part of the back of a stone step, dressed to fit into the rebate of the upper step, as *a a*, Fig. 492. When there is no rebate, the part of the under-side of the step, dressed to fit over the edge of the lower step, is called the back-joint. It is usually from 1 to 2 in. wide.

The term is also applied to the part of the back-edge of a landing or step against which a wood or paved floor abuts, and which is dressed to make a close joint.

*Back-lining of a Boxing.*—The piece of framing which forms the back part of the *boxing*. It should be tongued to the architrave grounds at one edge, and to the inside lining of the sash-frame at the other.

493.




*Back-lining of a Sash-frame.*—The part of a cased *sash-frame* next the wall, opposite the pulley-stile.

*Back of a Window.*—The part between the sill of the sash-frame and the floor. When this part is recessed into the wall, the sides are called elbows. See Fig. 493.

BACKER. Fr., *Ardoise à dossier;* Ger., *Unterschiefer;* Ital., *Lavagna stretta.*

A narrow slate laid on the back of a broad, square-headed slate, at the spot where a course of slates begins to diminish in width, is called a backer.

BACK-LASH. Fr., *Jeu;* Ger., *Todter Gang, Spielraum;* Ital., *Retrocolpo.*

See Reaction.

BACK-LINKS.

See Parallel Motion.

BACKING. Fr., *Remplage;* Ger., *Füllung;* Ital., *Ripieno;* Span., *Ripio.*

Backing is the hearting or internal mass of a wall faced with material of a superior quality. The filling over the haunches of a vault or arch is also termed the backing. Filling with earth or other material behind a wall to strengthen it against heavy shocks, as behind a *sea-wall* or between the walls of a *traverse*, is termed backing up.

*Backings* are slips of wood, fixed against rough walls, to which are attached wood linings or other finishings.

BACKWATER. Fr., *Eau dormante;* Ger., *Stauwasser;* Span., *Remanso.*

Water held back in a stream or reservoir by some obstruction, or water thrown back by the turning of a water-wheel, is called backwater.

BADIGEON. Fr., *Badigeon;* Ger., *Kitt aus Steinstaub und Gyps;* Ital., *Stucco;* Span., *Betun.*

Badigeon is the name given to any mixture for stopping holes in stone or wood work, for the purpose of hiding defects. The badigeon used for stonework is composed of plaster and freestone, well mixed and ground together. The badigeon employed for woodwork is sawdust and strong glue, or putty and chalk.

BAG.

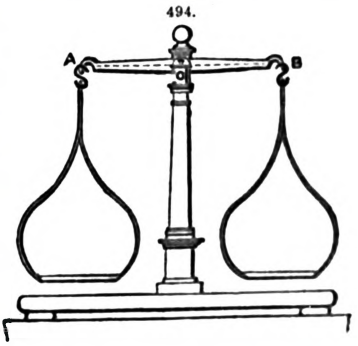
A bag is a measure reckoned equal to a Winchester bushel striked, or 2150·42 cub. in. Twenty-five bushels or bags make a hundred, or ton, of lime. A bag of plaster of Paris is reckoned at 14 lbs., and eight bags equal a bushel nearly.

BALANCE. Fr., *Balance;* Ger., *Wage;* Ital., *Bilancia;* Span., *Balanza.*

An apparatus for weighing bodies is termed a *balance;* in its original and simplest form, Fig. 494, it consists of a beam or lever A B, suspended exactly in the middle, O, with a scale or basin of precisely equal weight, hung to each extremity A, B.

In the balance, Fig. 494, where any two equal weights whatever, placed one at each extremity, are to be in equilibrium, it is requisite, first, that the balance preserve its equilibrium when it carries no weights; secondly, that the two arms be of equal length. For, let M, N, be the moments of the two parts of the balance when it has no weights appended; *a*, *b*, the lengths of the two arms; P, P, the weights which are in equilibrium upon it. Then, we must have $M + P\,a = N + P\,b$; whence, $P\,(b - a) = M - N$. And, since the equation must hold, whatever be the value of P, we have, necessarily, $M = N$, $a = b$. If either of the two specified conditions is wanting, the balance is said to be *false;* but it may still be made to serve justly to determine the weight.

494.




For the first defect is easily corrected, by giving an equipoise to the naked balance, through the addition, in one of the scales, of such a weight as will produce an equilibrium. The second defect is obviated by placing the body to be weighed, first in one scale and then in the other; its just weight will be a mean proportional between the two different marked weights, that have served to balance it. For if the weight P, placed successively in the two scales, is balanced by the two weights Q, Q', we shall have $\left\{\begin{matrix} P \times a = Q \times b \\ P \times b = Q' \times a \end{matrix}\right\}$, whence, by multiplying these equations together, we have $P^2 = Q \times Q'$, and hence the weight of P becomes known in terms of the registered weights Q, Q'.

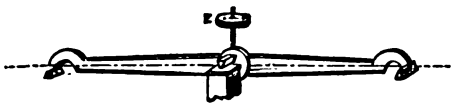
There is also another mode of making a false balance serve exactly to ascertain the equality of two weights. This method, invented by Borda, consists in placing the two weights successively in the same scale of the balance, and counterpoising them by the same weight placed in the other scale. If the two weights have, in the two successive weighings, been in equilibrium with the same counterpoise, they are necessarily equal to one another. Let the first weight be P, and let it be in equilibrium with the marked weight Q. We cannot conclude at once that P = Q, because we are supposed not to be sure of the justness of the balance. Let the second weight be P′, and let this, also, be in equilibrium with the same marked weight Q; and here, too, for the same reason, we cannot say that P′ = Q. But we may, with certainty, affirm that P = P′; because these two weights, being in equilibrium with the same marked weight Q, under the same circumstances, cannot but be equal. If P be a known standard weight, say of 100 lbs., and P′ an irregular piece of metal, the weight of which was sought, then we know that P′ = 100 lbs., without knowing the weight of Q. Since it is physically impossible to secure, with the utmost degree of precision, the perfect equality of the lengths of the arms, A O, O B, Fig. 494, and of the moments M, N, it will always be well to employ this method of two weighings, when it is wished scrupulously to ascertain the true weight of a quantity according to a given stand of weights.

The first method gives also the relations of the arms of the beam to each other. The body to be weighed is placed on one of the scale-boards, and counterbalanced by marked weights; let P be the weight thus obtained. The body is then placed on the other scale-board; let Q be the weight necessary to produce equilibrium. If Q be equal to P, then it is exactly the weight of the body. If this be not the case, let $x$ be the weight of the body to be weighed and $a$ and $b$ the lengths of the arms. In the first instance $x\,a = \mathrm{P}\,b$; [1] and in the second $x\,b = \mathrm{Q}\,a$, [2].

If these equations be multiplied member by member, and the common factors $a$ and $b$ cancelled, the result will be $x^2 = \mathrm{P\,Q}$, whence $x = \sqrt{\mathrm{P\,Q}}$, [3]; that is to say, that the real weight of a body is the geometrical mean between the weights found in the above manner. We obtain in addition, by dividing equation [1] by equation [2], the result $\frac{a}{b} = \frac{\mathrm{P}\,b}{\mathrm{Q}\,a}$, or $\frac{a^2}{b^2} = \frac{\mathrm{P}}{\mathrm{Q}}$, or lastly $\frac{a}{b} = \frac{\sqrt{\mathrm{P}}}{\sqrt{\mathrm{Q}}}$, [4]; therefore the arms of the beam stand in the same relation to each other as the square roots of the weights which were placed at the extremities of the opposite arms. From the third and fourth equations can be deduced $\frac{a}{b} = \frac{x}{\mathrm{Q}}$, or $\frac{a}{b} = \frac{\mathrm{P}}{x}$. If, for instance, P = 1ᵏ·350 and Q = 1ᵏ·362, then $x$ = 1ᵏ·35598, or nearly $x$ = 1ᵏ·356, and $\frac{a}{b}$ = ·995594, or $\frac{a}{b}$ = ·996 nearly.

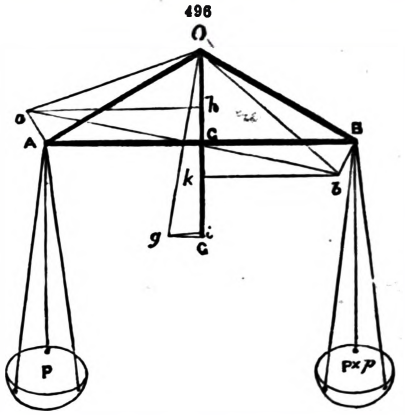
In order that a balance *be just*, it is not sufficient that the two equal weights are in equilibrium; but the inequality of weight must also have the power to overcome the friction of the fulcrum. For this purpose the beam must encounter no resistance in its revolution round the fixed point,

495.



or there must be no friction between the beam and its supports; for any friction would necessitate an increased weight of the body to produce equilibrium. In exact balances, the beam is supported, upon polished surfaces of steel or agate, by steel blades, Fig. 495. By this means the friction is reduced to a minimum.

496




The perfection of the balance, and the facility of managing it, require other conditions. In the first place, for every, the smallest, inequality of the two weights, the needle of the balance should slowly incline itself, stopping in a position oblique to the horizon, without going completely down. Further, if the balance is in a state of equilibrium, and if the needle is accidentally made to incline itself, it ought not to stop in that inclined position, nor completely to go down, but slowly to reassume its vertical position.

The fulfilment of these conditions depends, above all, upon the relative position of the three points O, C, G, Fig. 496, of which O is the centre of motion, G the centre of gravity of the beam of the balance, C the intersection of the vertical line O G with the horizontal line A B, which joins the points of suspension of the two scales.

The most advantageous situation of the three points O, C, G, is readily determined from the succeeding derived equations. The equilibrium of a balance having been disturbed, by the addition of a very small weight $p$ to one of the equal weights P, P, that are weighed in it, to determine the inclination, which will thence ensue, in the needle of the balance.

Suppose that, by the addition of the small weight $p$ to the weight P, hanging from the point B, the beam passes into the position $a\,\mathrm{O}\,b$; and let the angle $\mathrm{A\,O}\,a = \mathrm{B\,O}\,b = \mathrm{G\,O}\,g = \theta$, and the angle $\mathrm{A\,O\,C} = \mathrm{B\,O\,C} = \alpha$; and from the points $a$, $b$, $g$, let there be drawn $a\,h$, $b\,k$, $g\,i$, perpendicular to O G, and let M be the weight of the beam.

Then, for the balance to be in equilibrium in the position $a\,\mathrm{O}\,b$, we must have

$$\mathrm{P} \times a\,h + \mathrm{M} \times g\,i = (\mathrm{P} + p) \times b\,k; \qquad [\mathrm{Y}].$$

$$\text{Now, } a\,h = \text{A O sin. } (\alpha + \theta) = \text{A O sin. } \alpha \text{ cos. } \theta + \text{A O sin. } \theta \text{ cos. } \alpha$$
$$= \text{A C cos. } \theta + \text{O C sin. } \theta;$$
$$b\,k = \text{A O sin. } (\alpha - \theta) = \text{A O sin. } \alpha \text{ cos. } \theta - \text{A O sin. } \theta \text{ cos. } \alpha$$
$$= \text{A C cos. } \theta - \text{O C sin. } \theta;$$
$$g\,i = \text{O G sin. } \theta.$$

Substituting these values in [Y], the equation of equilibrium, we shall have,

$$\tan.\,\theta = \frac{p \times \text{A C}}{(2\,\text{P} + p)\,\text{O C} + \text{M} \times \text{O G}};$$

or putting M′ for the weight of the loaded balance, so that $\text{M}' = \text{M} + 2\,\text{P} + p$, we shall have more briefly

$$\tan.\,\theta = \frac{p \times \text{A C}}{\text{M}' \times \text{O C} + \text{M} \times \text{C G}}.$$

The mobility of the balance, therefore, will be the greater, the longer are its arms, the nearer together are the three points O, C, G, and the less it is loaded. If $\text{O C} = o$, then, $\tan.\,\theta = \frac{p \times \text{A C}}{\text{M} \times \text{C G}}$; and consequently the mobility of the balance is the same, whatever be the load which it carries. If, at the same time, O C = zero, and G C = zero, so that the three points O, C, G, coincide, then $\tan.\,\theta = \infty$ or infinity; and then for every, the smallest, derangement of the equilibrium, the needle of the balance will go down, and describe a quadrant of a circle, so as itself to become horizontal. And if O C and C G were negative, tan. $\theta$ would become negative, and the needle, still going down, would describe more than the quadrant of a circle. It is evident that these constructions of the balance are faulty.

If the needle or pointer of a balance, which is in perfect equilibrium, be made to incline at the angle $\theta$, to find the force with which the beam tends to resume the position of equilibrium. Let S be the *moment of* INERTIA, of the loaded balance, with respect to the axis of motion. The accelerating force, with which the beam will tend to turn round in the direction $a$ A $b$ B, to place itself again in the position A O B, will be

$$= \frac{\text{P} \times a\,h - \text{P} \times b\,k + \text{M} \times g\,i}{\text{S}}.$$ See INERTIA, moment of.

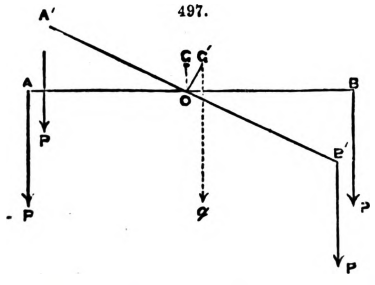
And substituting the values of $a\,h$, $b\,k$, $g\,i$, before found, the force sought is found to be

$$= \frac{\text{sin. } \theta}{\text{S}}\,(2\,\text{P} \times \text{O C} + \text{M} \times \text{O G})$$
$$= \frac{\text{sin. } \theta}{\text{S}}\,(\text{M}' \times \text{O C} + \text{M} \times \text{C G}).$$

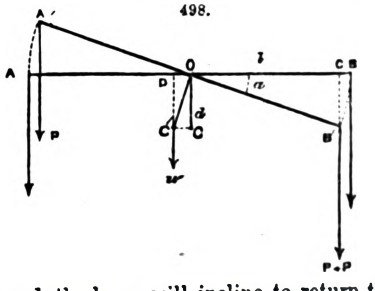
It must be observed, in computing the moment of inertia S, that the masses of the weights P, P, which hang freely from the points A, B, must be understood to be concentered in these points. If O C = O G = zero, the restoring force vanishes; in that case, the balance is said to be indolent; indeed it stops altogether, the needle resting indifferently in any position. But if O C and C G are negative, the restoring force is negative; and then the balance is said to be unstable, because, for every, the smallest, inclination of the pointer, instead of resuming the position of equilibrium, it deviates more and more from it, and goes completely down.

The weight of the beam may be considered as applied to the centre of gravity G, Figs. 497, 498. If this point be removed from the perpendicular to G′, by a slight movement of the beam, it

497.




498.




will be raised. The force of gravity causing it to descend, the beam will incline to return to its first position, which it will retain after a series of oscillations. This third position is the one which should be adopted.

The centre of gravity of the beam must not, however, be situated too far below the axis of suspension; for we should then have a so-called *inert* balance. This is easily accounted for. Let A B be the points of suspension of the scale-boards, and let them be placed in a horizontal line passing through the point of suspension O, or, more exactly, through the axis of suspension.

Suppose a weight P be applied to A, and a weight $\text{P} + p$ to B. Let $q$ be the weight of the beam, which may be considered as applied to G. The excess of weight $p$ applied to B will firstly lower the arm O B of the beam; but if this excess be not too great, the beam will soon attain a certain position A′ B′, where it will finally remain in equilibrium after several oscillations; this position can be determined.

If G′ be the new position of the point G, draw the horizontal G′ I, and the perpendiculars A′ C and B′ D. Considering the moments of the forces with regard to the point O, and taking into account the direction of the rotation which each force tends to produce, the result will be

$$(\text{P} + p) \times \text{O D} = \text{P} \times \text{O C} + q \times \text{G}'\text{I}. \qquad [5]$$

But A′ O B being a straight line, the same as A O B, and the arms A′ O and B′ O of the beam being equal, it follows that O C is equal to O D; the terms P × O D and P × O C disappear from

the above equation, leaving $p \times OD = q \times G'I$. If $\delta$ be the distance GO or G'O; $b$ the length OB or OA of the arm of the beam, and $\alpha$ the angle BOB' or its equal GOG', then

$$OD = b \cos. \alpha \text{ and } G'I = \delta \sin. \alpha.$$

The condition of equilibrium then becomes $pb \cos. \alpha = q\delta \sin. \alpha$, from which is deduced $\tan. \alpha = \frac{pb}{q\delta}$; [6]. It is, therefore, evident that if the distance GO or $\delta$ be too great, the value of tan. $\alpha$, and consequently of $\alpha$, for the same excess of weight $p$, might be very small; the beam would then remain in equilibrium, in a position but little different from its primitive position, with which it might be confounded. The balance would, therefore, not be sensible enough.

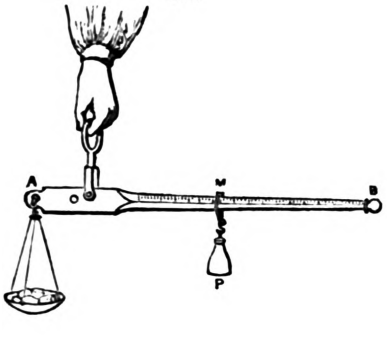
The angle $\alpha$ may be regarded as the measure of sensibility of the balance; it will increase as the weight $q$ of the beam diminishes, as the arm $b$ lengthens, and as the distance $\delta$ from the centre of gravity of the beam to the axis of suspension becomes shorter. In precise balances, the distance from the centre of gravity of the beam to the axis of suspension can be changed by means of a nut E moving up and down a screw, the axis of which is perpendicular to the direction of the beam, Fig. 495. The angle described by the beam is indicated by a needle, fixed perpendicularly; the end of this needle moves round a graduated arc. It is now evident that, by placing the points of support A and B in a horizontal line, passing through the axis of suspension, the sensibility of the balance does not become affected by the weight to be estimated. It is by virtue of this fact that the terms $P \times OD$ and $P \times OC$ disappear from the equations of the moments. The case would be altered if the point O were above or below the horizontal AB: the lengths OD and OC would then no longer be equal; the weight P would remain in the equation, consequently the angle $\alpha$, and with it the sensibility of the balance, would depend upon the weight of the scale-boards. To diminish as much as possible the friction, the scale-boards are suspended by hooks resting on blades at the extremity of the beam, as seen in Fig. 494.

The lever-balance, Fig. 499, is also a lever of the first order. The materials to be weighed are placed in a scale-board, suspended at the extremity B of one of the arms of the beam; and equilibrium is established by means of a slider A, which moves along the other arm. If the beam be suspended in such a manner that the friction may be omitted, as shown in the figure, and if the centre of gravity of the beam lie in a perpendicular from the point of suspension O, equilibrium will ensue when P is the weight of the materials to be weighed and $p$ that of the slider,

$$P \times OB = p \times OA, \text{ whence } P = p \times \frac{OA}{OB}.$$

The quantities P and OA being constant, it is evident that the weight Q is proportional to the distance OM between the slider and the point of suspension. For convenience, the arm OB is divided into a certain number of equal parts, at each of which is marked the weight which produces equilibrium when the slider is at that spot. This kind of balance has sometimes two rings for suspension, and consequently two corresponding systems of blades; one or the other ring is used, according to the nature of the substances to be weighed; if these be light, the ring farther from the point B, to which the scale-board is attached, is used. For heavy matters, the ring nearer B is employed. The arm OA, in this case is divided in two different manners.

499.

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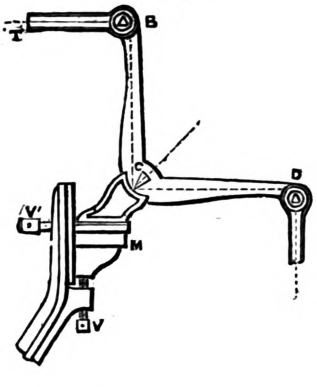


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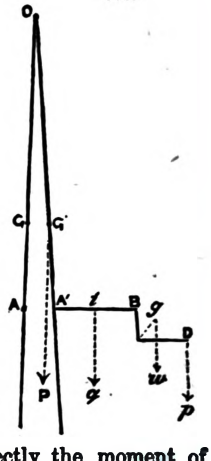



BALANCE, *Moment.*—An apparatus invented by Didion to measure directly the moment of the weight of a *ballistic pendulum* with regard to the axis of suspension. This apparatus was adopted in 1857 for testing powder in powder manufactories in France. It consists of a bent lever BCD, Fig. 500, in which the arms CB and CD are equal, and form an angle slightly greater than a right angle. At the extremity B of one of the arms is joined, by means of blades, an inclined rod T, which can be fixed or jointed to the ballistic pendulum; at the extremity D of the other arm is jointed, also by means of blades, a second rod, supporting a scale-board for the reception of weights. The bent lever rests at C upon a support M, which can be fixed to the structure bearing the pendulum. This support can be moved either in a direction parallel to the arm CB, or in a direction perpendicular to it, by moving the screws V or V'. Let OA, Fig. 501, be the perpendicular from the point of suspension of the ballistic pendulum, containing the centre of gravity G. suppose the straight line OGA brought to the position OG'A', forming an acute angle $\alpha$; a rod A'B, jointed at A' to the pendulum and at B to one of the arms of the balance, is placed perpendicularly to OA', and makes consequently an angle $\alpha$ with the horizon. The bent lever is so

constructed that when the arm C B is placed parallel to O A', the other arm C D is horizontal, or the angle B C D is equal to $90° + \alpha$. In the scale-board suspended to D a weight is placed sufficient to maintain equilibrium in the position just indicated; this weight will give the weight P of the pendulum, applied at G', in relation to the point of suspension O.

The theory of this apparatus is easily understood. Take, firstly, the equilibrium of the pendulum and the moments of the forces acting upon it, with regard to the axis through O. The suspension being effected by means of blades, the reaction of the supports may be considered as zero; there then remain but the moment of the weight P and the moment of the reaction R exercised at A' by the rod, in the direction A'B; if we make O A = L and O G = $l$, we get

$$P l \sin. \alpha = R L. \qquad [1]$$

Take, secondly, the equilibrium of the rod A'B; let R' be the reaction exercised on the rod, at B, by the bent lever, and let $q$ be the weight of the rod, applied to its centre of gravity $i$; if we move the forces R, R' and $q$ in the direction A'B, we shall obtain

$$R + q \sin. \alpha = R'. \qquad [2]$$

Then the rod receives from the pendulum a reaction R equal and opposite to that which it exerts on the pendulum.

Take, lastly, the equilibrium of the bent lever, and take the moments with regard to the axis through C; the moments of the reaction of the supports may here also be considered as zero, as well as the friction of the blades at B and D. The moment of the reaction R', exercised at B, by the rod A'B, must be rendered equal to the sum of the moments of the weight $p$ of the scale-board suspended at D, and of the weight $\pi$ of the levers, applied to the centre of gravity $g$. If $\lambda$ be the length of the lever-arm C B, $\lambda'$ that of the arm C D, very little different from $\lambda$, and $\delta$ the distance $g$ C, the point $g$ lying in the bisecting line of the angle B C D, then

$$R' \lambda = p \lambda' + \pi \delta \cos. (45° + \tfrac{1}{2} \alpha). \qquad [3]$$

By eliminating R and R' from equations [1], [2], and [3], and seeking the value of the moment P$l$, we find:—

$$P l = \frac{L}{\sin. \alpha} \left[ p \frac{\lambda'}{\lambda} + \pi \frac{\delta}{\lambda} \cos. (45° + \tfrac{1}{2} \alpha) \right] - q L. \qquad [4]$$

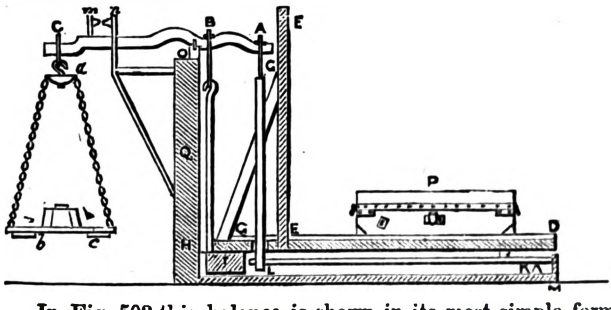
In the balance for moment, constructed according to Didion's design, $\alpha = 5° 44' 21''$, whence sin. $\alpha = 0{\cdot}1$ and cos. $(45° + \frac{1}{2} \alpha) = 0{\cdot}6708$. Also $\lambda = \lambda' = 0^m{\cdot}2$, therefore

$$P l = 10 L (p + 3{\cdot}354 \pi \delta) - q L. \qquad [5]$$

This apparatus gives the moment P$l$ within at least one ten-thousandth of its value. But it is of the greatest importance that the arms of the lever be exactly equal, and that their length be known, for an error of one-tenth of a millimètre in one of their lengths would give rise to an error of one five-hundredth in the calculation of the moment sought. In order to test the equality of the lever-arms, the bent lever should be placed in two positions, so that each arm occupies alternately a horizontal position; if the arms were unequal, two different weights $p$ and $p'$ would be necessary to produce equilibrium in each case. If this be the case, Didion substitutes for $p$, $\sqrt{p p'}$; but this rule, which is exact when applied to the common balance, is here only approximative. See 'Traité d'Artillerie,' par Didion.

A *Weighing Machine* is a balance employed chiefly in shops, warehouses, and railways for weighing heavy weights. The beam A B C, Fig. 502, moves round a horizontal axis passing through O; at the extremity C is suspended the scale-board in which the weight $p$, destined to produce equilibrium with the weight P, is placed. The weight to be determined is placed on a horizontal plane D E, to which is attached on one side a vertical partition E F, to protect the balance from injury; this is fastened to a horizontal bar T, the end of which is shown in the figure, by oblique bars G G. T is suspended from the short arm of the beam by a rod B; D E also rests at I upon a lever K L, movable at I and suspended by the rod L A from another point A of the same arm of the beam. The lower part of the machine is enclosed in a case, which is omitted in the figure. The lower stage M N supports the blade K, upon which the lever K L turns; and the vertical partition N Q supports the axis of suspension of the beam. When there is no weight either upon E D or upon $b c$, the point $m$, fixed upon the arm O C, must be exactly opposite the point $n$, fixed to the frame-work of the machine. As this is, in reality, seldom the case, a small weight is placed in the cup $a$, suspended to C, till $m$ is opposite $n$; this weight is called the tare. A weight to be weighed must be placed on D E; weights are then placed on the scale-board $b c$ till the points $m$ and $n$ are opposite. The weight $p$ on the scale-board is exactly a tenth of the weight P on the stage D E.

502.

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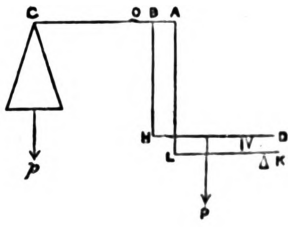
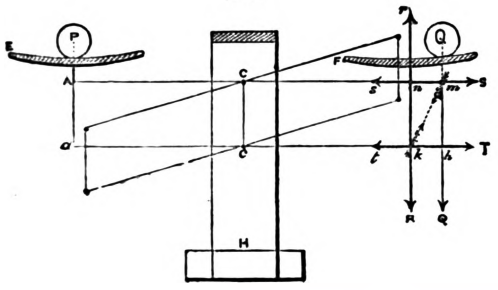



In Fig. 503 this balance is shown in its most simple form. The dimensions of the different parts are such as to produce the proportion O B : O A = K I : K L = 1 : $n$. [1]

The relation of O B to O C is generally $\frac{1}{10}$. When the apparatus is set in motion, D H remains horizontal. If the points B and H are lowered a short distance $h$, by virtue of the above proportion the point A lowers itself $n\,h$. It will be the same with the point L; consequently, in the same proportion, the point I will be lowered the distance $h$, like the point H; and I H will remain horizontal. The actual work of P will be $+ P\,h$, as the stage is lowered $h$. But the point C will be raised $10\,h$, as O C = 10 O B; the actual work of $p$ will therefore be $-10\,p\,h$. The actual work of the reactions exercised by the points of support I K O is zero, if the friction be omitted. The other forces that influence the system are mutual, equal in pairs, and having opposite signs, and their virtual actions cancel one another in the summing up. There then remains $P\,h - 10\,p\,h = 0$, whence $p = \frac{P}{10}$. In reality, the four points A, B, C, O, Fig. 502, are not in the same horizontal plane; but if they are projected on a horizontal plane passing through O, as in Fig. 503, A B C, the same reasoning holds good.

*Conditions of Equilibrium in Roberval's Balance.*—A $n$, $a\,k$, Fig. 504, are two equal and parallel bars turning at their middle points about pivots C, $c$, which are in the same vertical line, and connect with the stand H C. The extremities of these bars are connected by means of pins A, $a$; $n$, $k$, with two other bars A $a$, $n\,k$, so as to allow of free motion about these points. Then, since A C, $a\,c$ are equal and parallel, A $a$ is equal and parallel to C $c$; and therefore A $a$, $n\,k$ will always be vertical in every position. In this balance, two horizontal rods are fixed to the vertical bars A $a$, $n\,k$, on which the weights P and Q are placed, and if these balance each other in one position, the equilibrium will remain undisturbed in every other position. On the same principle the balances now in general use are constructed, and we will prove that if the weights P, Q are equal they will balance each other in whatever part of the scale-pans, E, F, they are placed. Suppose the weight P to be placed in the scale E, immediately over the rod A $a$; and an equal weight Q in the other scale F acting at any distance C $m$ from the centre. At $n$ introduce two equal and opposite forces R, $r$, acting vertically in opposite directions, each equal to Q. Also introduce two pairs of equal and opposite forces S, $s$; T, $t$; each of these forces having the same proportion to Q as $m\,k$ to $n\,m$. These six forces will manifestly balance each other, and not affect the equilibrium. Now the forces Q and $s$ being proportional, $m\,h$, $m\,n$ are equivalent to a force represented by the diagonal $m\,k$. In like manner, $r$ and T are equivalent to the same force $k\,m$ acting in the opposite direction. Hence the forces Q, $s$; $r$, T, mutually destroy each other; and, therefore, the force Q is equivalent to the equal force R acting in the direction $n$ R, and the two forces S and $t$ acting in the directions C $n$, $k\,c$. But the forces S, $t$ only produce pressure on the pivots C, $c$, and have no effect in turning the bars round. And since P and R are equal and at equal distances from C, they will balance each other.

504.

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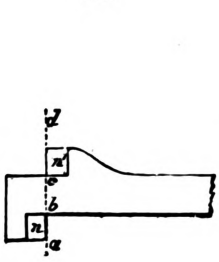



506. 507.

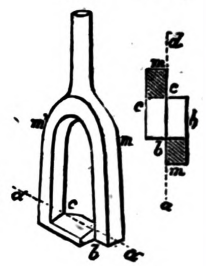



Fig. 505 represents the extremity of this beam seen from above; $n\,n$ are two blades, inclined in contrary directions, their edges $a\,b$ and $c\,d$ are placed in a straight line in the lower plane of the beam. This extremity enters a stirrup, forming the lower end of the side A A', and which is represented in Fig. 506 in perspective, and Fig. 507 in plan. Its lower cross-bar is a blade, the edge of which, $b\,c$, is turned upwards; the two prongs $m$ and $m'$ are so arranged that this edge is on the outer side at $m$ and on the inner at $m'$. When the end of the beam is in connection with the stirrup, the edge $a\,b$ of the blade $n$ rests on the outer face of the prong $m$, the edge $c\,d$ of the blade $n'$ rests on the inner face of $m'$, and the lower face of the beam rests on the edge $b\,c$ of the blade forming the cross-bar of the stirrup. The edges of the three knives thus form a prolongation of each other, and each bears on a corresponding plane. It follows, that in all portions of the parallelogram the contact takes place along this same edge, which thus forms the axis of articulation, without producing an appreciable amount of friction. The opposite end of the beam is jointed in the same manner to the stirrup, which forms the lower end of the side B B'. At O' the jointing is of the same nature, with this difference, that the stirrup is fixed. This system of jointing gives to the parallelogram the desired sensibility. The lower beam and the greater part of the lateral sides are generally concealed by the body of the balance, as shown in Fig. 508. The conditions of stability and sensibility are otherwise the same as in the ordinary balance; the centre of gravity of each beam, and particularly of the upper beam, must be a short distance below the axis of suspension of that beam.

508.

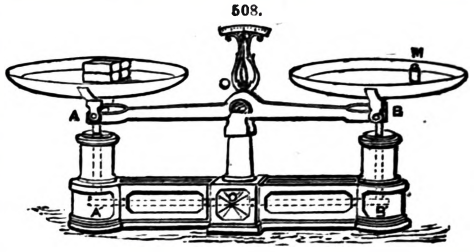
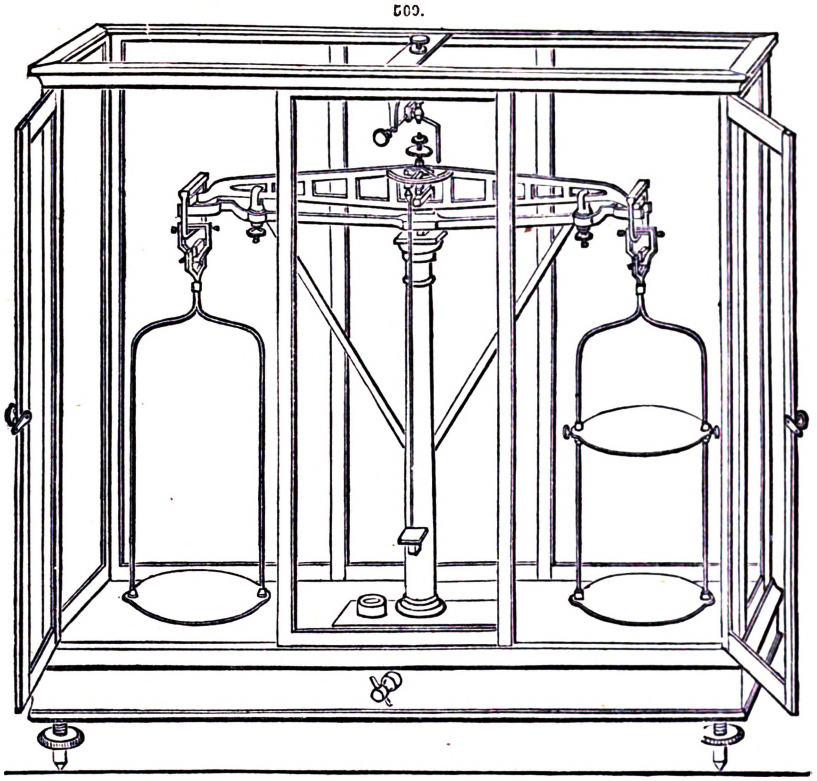


Fig. 509 represents an *assay balance* of great delicacy and precision, with the glass case enclosing it. In front, and slightly projecting from the stand, is seen the end of a lever, by means of which the beam can be raised in order to relieve the knife-edged fulcrum, upon which it rests, from

509.



fatigue and wear when the instrument is not in use. At the upper part will be observed a small mechanical contrivance resorted to by some makers, though not in general use. In front of the beam is a horizontal graduated semicircle, over which a little metallic needle can be made to travel with the aid of a pin, worked by a button on the exterior upper surface of the case. By shifting this needle to the right or to the left, the equilibrium may be obtained with much accuracy, while the readings on the graduated semicircle show the increments or decrements of weight. See HYDRAULIC MACHINES. LEVER. WEIGHING MACHINES.

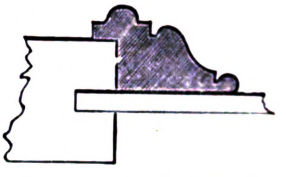
BALANCE-VALVE. FR., *Soupape à bascule;* GER., *Entlastcter Schieber;* ITAL., *Valvola bilanciata;* SPAN., *Válvula autamatora.*

See VALVES.

BALECTION. FR., *Moulure;* GER., *Fenster oder Thürverkleidung;* ITAL., *Modanatura.*

*Balection, bolection.*—A term applied to mouldings which project beyond the face of the work which they decorate, Fig. 510. They are principally used for external doors.

510.



BALK, BAULK. FR., *Poutre, Guéret;* GER., *Balken;* ITAL., *Trave;* SPAN., *Viga.*

In engineering, the ridge or bank between two excavations; also a term applied to timber in the log, roughly squared, and before it is sawn up for use; and sometimes used to designate the horizontal timbers in an open roof.

BALL-AND-SOCKET JOINT. FR., *Genou de charnière;* GER., *Kugelgelenk;* ITAL., *Snodatura sferica, Nocella;* SPAN., *Juego de nuez.*

See JOINTS.

BALL-COCK. FR., *Robinet modérateur;* GER., *Zulass und Absperrhahn;* ITAL., *Chiave a galleggiante;* SPAN., *Válvula flotante.*

See WATER-SUPPLY.

BALL-LEVER. FR., *Levier à bascule;* GER., *Regulirungs brebel;* ITAL., *Leva a contropeso.*

See WATER-SUPPLY.

BALL-VALVE. FR., *Ventouse;* GER., *Ablass;* ITAL., *Valvola pallata.*

See WATER-SUPPLY.

BALLAST. FR., *Lest;* GER., *Ballast;* ITAL., *Stiva, Ghiaia;* SPAN., *Lastre.*

Ballast is a term applied to gravel, stone, or other material used for loading ships, to give them steadiness in the water when sailing without a cargo, or when the cargo is not of sufficient weight.

In *civil engineering*, a layer of broken stone or coarse gravel, from 6 to 18 in. in thickness, laid above the formation-level of roads and railways, where it answers the purpose of a foundation for the road-metal in the former, and for the sleepers and permanent way in the latter. Originally the material used for this purpose was of the same description as that used for ballasting ships, hence the term.

Thames ballast is the gravel dredged from the bed of the river Thames, and is used for ships' ballast, making concrete, formation of roads, &c.

Where stone and gravel are scarce, clay burned to the hardness of at least ordinary bricks is used instead of the ordinary gravel or stone ballast, the process being as follows:—

Clay as used for the manufacture of bricks is dug and slightly tempered to make a homogeneous mass; a log of wood is fixed upright in the ground, from which a flue, technically termed a "live hole," of 8 or 9 in. in diameter, and about 7 ft. long, according to the size of the heap to be burned, is formed of bricks on edge, or old drain-pipes, on the upper side of which, at the end next the wood, is left an opening. Pieces of wood are next piled around the upright log, in a conical form, about 4 or 5 ft. in diameter at the base, and about 4 ft. high. Over this cone of wood is placed about half-a-ton of coal, and on the coal a coating of clay 6 to 8 in. thick. The whole is then set on fire through the horizontal flue.

As the wood burns down, coals are thrown in until all becomes in a state approaching incandescence. It is then ready to form the core for the reception of another coating of clay; and as the burning proceeds, coal and breeze are added to feed the fire, then another coating of clay, and so on, until the size of the heap becomes such as to render it inconvenient to add more. The burning should proceed gradually at first, as in brick-making, to expel the moisture, after which the heat may be urged. When the mass is thoroughly burned through, it should be left to cool, and afterwards broken into pieces of the size required. From $\frac{3}{4}$ of a cwt. to 1 cwt. of coal is required to burn a cubic yard of clay; or, according to some authorities, about 11 cub. yds. of breeze, and 4 tons of coal, including small coal or slack, is required to burn 100 cub. yds. of clay.

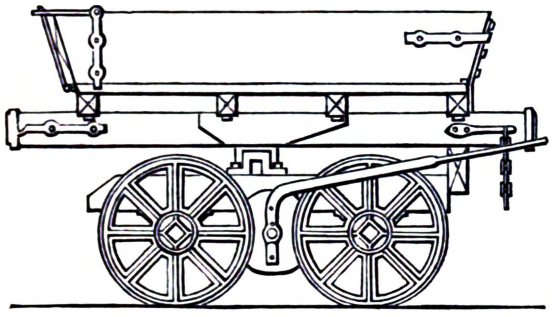
A cubic yard of clay, measured in the solid, before digging, will, when burned and broken up, occupy a space of $1\frac{1}{4}$ to $1\frac{1}{2}$ cub. yd., and weighs about a ton.

About 22 cub. ft. of Thames ballast, 21 of broken granite, and from 22 to 27 cub. ft. of other stones, when broken, weigh a ton.

BALLAST-WAGON. Fr., *Waggon à lest;* Ger., *Ballast Wagen, Kieswagen;* Ital., *Carro da Ghiaia;* Span., *Wagon para lastre.*

A ballast-wagon is a wagon employed in removing earth in excavations and similar works. They are usually made to hold 2 to 3 cub. yds. Ballast-wagons should be made with springs, as without springs they increase the wear and tear of the rails considerably, and add to the expense of maintaining the way. Figs. 511, 512, show forms of ballast-wagons generally in use.

511.



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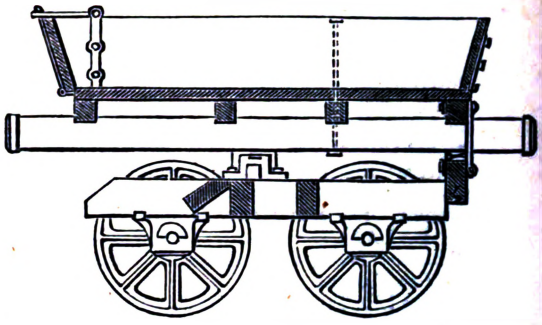


BALUSTER. Fr., *Balustre;* Ger., *Docke einer Treppenlehne;* Ital., *Balaustro;* Span., *Balaustre.*

A small pillar, a series of which, fixed under the coping of the parapet of a bridge, or otherwise, is called a balustrade. It also applies to the pillars of wood or iron which support the hand-rail at the side of a stairs.

BALUSTRADE. Fr., *Balustrade;* Ger., *Balustrade;* Ital., *Colonnata di balaustri;* Span., *Balaustrada.*

See Baluster.

BANDING-PLANE. Fr., *Rabot à rainure;* Ger., *Nuthhobel;* Ital., *Pialla da intorsiatore;* Span., *Cepillo de Bocel.*

A banding-plane is a plane used for cutting out grooves and inlaying strings and bands in straight and circular work.

BANKER. Fr., *Etabli;* Ger., *Werkbank;* Ital., *Ceppo;* Span., *Banco de cantero.*

The bench or table upon which bricklayers and stonemasons prepare and shape their materials.

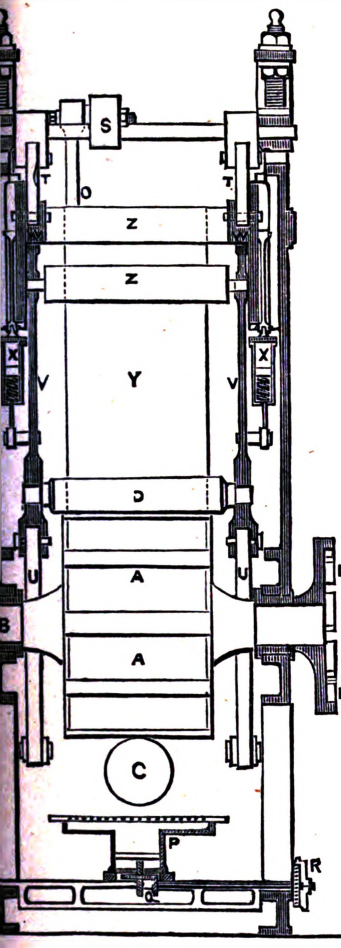
BANK-NOTE PRINTING MACHINE. Fr., *Machine à imprimer les billets de Banque;* Ger., *Presse zum Drucken der Cassenscheine;* Ital., *Macchina per stampare i biglietti di Banco ed altri.*

The Bank-Note Printing Machine, invented by Thomas Grubb, of Dublin, and described by him in a paper read before the Institution of Mechanical Engineers, is shown in Figs. 513 and 514; Fig. 514 is a side elevation, and Fig. 513 a vertical section taken at right angles to Fig. 514.

The machine consists of a horizontal polygonal cylinder A, Figs. 513 and 514, of twenty sides, on ten of which are held the ten engraved plates from which the notes are to be printed. These engraved plates are held in position in dovetails formed by ten plain plates screwed upon the ten

intermediate sides of the polygon. The plates and polygon are maintained at the proper temperature for working, by steam admitted inside the hollow polygon through the back-bearing B, Fig. 513.

513.

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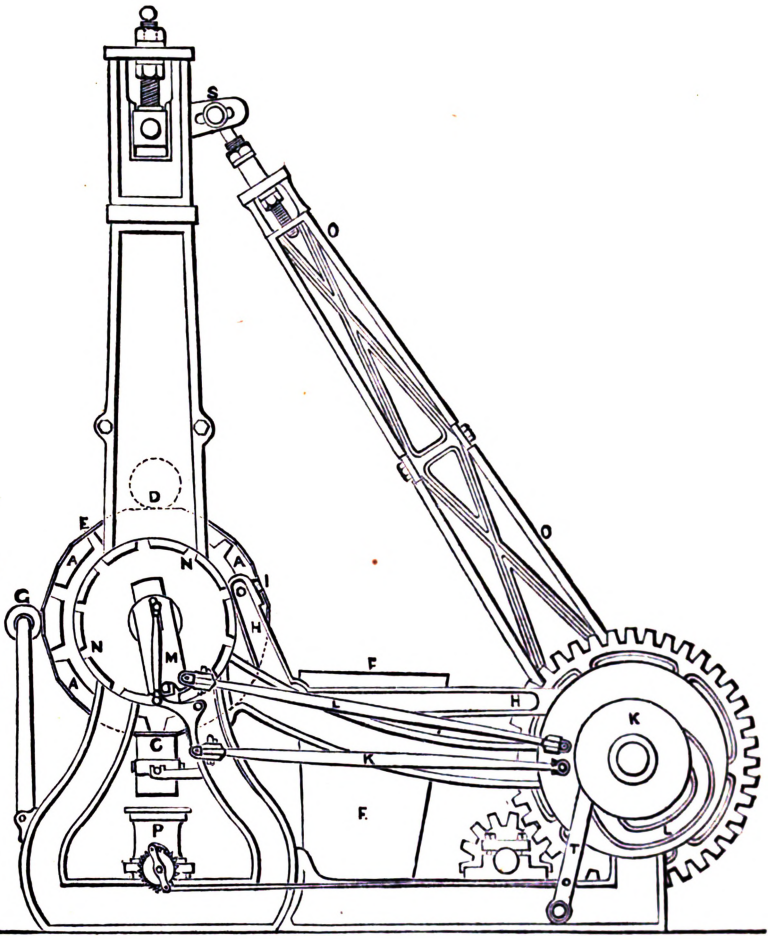



At the ordinary rate of working, each impression occupies ten seconds; and the polygon is held stationary during eight seconds of the time, and during the remaining two seconds it is turned round through $\frac{1}{10}$th of a revolution, in the direction shown by the arrow in Fig. 514, so as to bring the next engraved plate to the top for being printed from. During the eight seconds that the polygon is stationary, the undermost plate at C is inked by the machine, the uppermost plate at D is printed from, and the plate at E has the wiping of its surface completed. The machine requires two attendants, one standing in the box F, who lays the paper, removes it after being printed, and observes that the work is proceeding satisfactorily; while the other gives the final wiping by hand to the surface of each plate as it comes into the position E, Fig. 514. The greater portion of the superfluous ink is wiped off by the machine, thereby lessening the labour of the final wiping by hand; this is done by means of the wiping-roller G, on which is wound a length of cotton cloth. This wiping-roller is stationary while the polygon is at rest; but on the polygon beginning to move, the roller presses against the surface of the previously inked plate, and, by turning in the opposite direction, wipes off the superfluous ink. When the surface of this roller becomes surcharged with ink, a length of the cotton cloth upon it equal to one round is torn off. By the revolution of the polygon, therefore, each plate on arriving at the bottom at C is inked, and as it proceeds upwards is first partially wiped by the machine at G, and afterwards finally wiped by hand at E, and on arriving at the top is printed from by the printing-roller D.

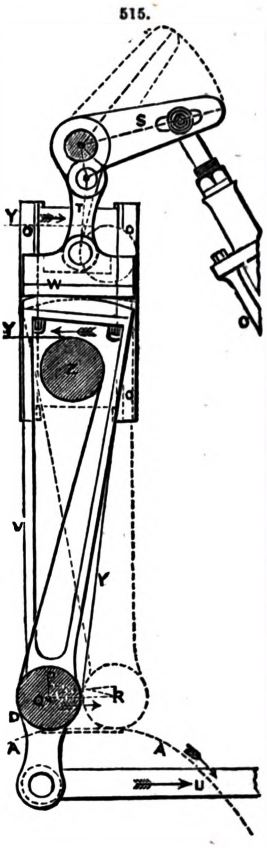
Several special contrivances are required for producing the respective actions of the machine, the principal of which are the apparatus for locking and turning the polygon, and for the motions of the printing-roller, and the inking apparatus.

At each printing the polygon is subjected to a heavy strain by the vertical pressure of the printing-roller D, Fig. 514, tending to turn it first in one direction and then in the opposite direction alternately, as the printing-roller passes over from one side of the centre to the other; it therefore requires to be very firmly locked during the time that it has to be held stationary for printing. This is effected by the locking-lever H, which, being lowered by its cam, inserts the steel tooth I into one of the ten spaces round the circumference of the polygon. The turning of the polygon through $\frac{1}{10}$th of a revolution between each printing is accomplished by the levers and cams K K and L L; one of these levers, K, alternately withdraws and protrudes the tooth J, while

the other, L, moves the carrier-box M through the required arc. The action of the levers H and K is so arranged, that as the tooth of the locking-lever is withdrawn, that of the turning-lever enters the toothed circular plate N, and *vice versâ*. The polygon is thus sure to be duly acted upon, and always under restraint, thereby ensuring against risk of accident, which might occur if ordinary means were employed for turning the polygon.

For working the printing-roller D, Figs. 513 and 514, the ordinary method of causing it to roll up an inclined plane into contact with the plate was inadmissible in the present machine, and the following arrangement has been adopted for the purpose. The roller is first caused to descend vertically at the proper time and with a sufficient pressure upon the plate, on which the paper to be printed is previously laid; next, the roller is carried horizontally over the surface of the plate, to produce the impression; then it is raised from the plate and withdrawn to its first position. The motion of the centre of the roller is, therefore, as shown by the dotted line P Q R in Fig. 515; and this motion is produced in the following manner. The vertical descending movement from P to Q is effected by the long trussed rod O and its double cam, acting on the bell-crank S and toggle-lever joint T. The horizontal traverse from Q to R is produced by the printing cams and their levers U acting upon the sectors V, Figs. 513 and 515. These sectors roll against inverted straight-edges W, and the bearings of the printing-roller D being concentric with the arcs of the sectors V, the roller is traversed horizontally over the engraved plate. The curved motion from R to P, in withdrawing the printing-roller and returning it to its original position, is produced by the joint action of the two sets of cams. The blocks W, against which the sectors V roll, slide vertically in grooves in the side frames of the machine; the under-side of these blocks is faced with a flat surface of hardened steel, against which rolls the upper segmental surface of the sectors, which is also made of hardened steel. These steel bearing-surfaces are retained in contact by the spiral springs X, Fig. 513, which carry the weight of the sectors, the printing-roller, and the levers U. The sectors are prevented from slipping in rolling against the blocks W, by means of bridle-levers, which admit of motion in other directions, but prevent slipping. An endless sheet of flannel Y passes round the printing-roller D and over the guide-rollers Z above, travelling in the direction shown by the arrows in Fig. 515; the upper rollers Z are carried by the sectors V and slide-blocks W.

515.



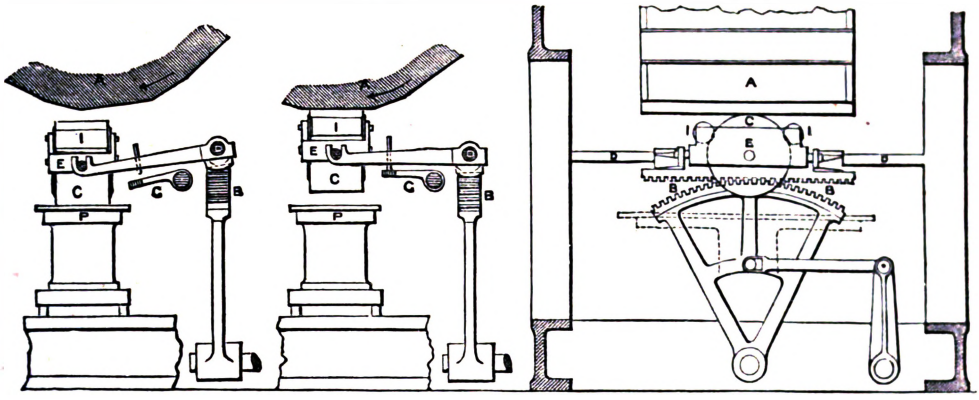

The inking of the engraved plates is performed by the inking-roller C, Figs. 513 and 514. Upon the capability of the machine to ink the engraved plates effectively depends its usefulness; and herein lay the main difficulty, and the reason of the failure of previous attempts at improvement. The difficulty was much enhanced by the circumstance that, in using the ink applicable to engraved plates, a portion of it becomes thickened and unfit for immediate use. In the ordinary hand-inking, this thickened ink collects in a ring on that part of the dabber which barely comes into contact with the plate during the inking; and this requires to be removed occasionally from the dabber by a knife or scraper, otherwise, by its mixing with the fresher ink, the quality of the work would be injured. In experiments made preliminary to constructing the present machine, a cylindrical roller was used for inking the plates by hand, and was supplied with ink from a perforated surface, through which the ink was caused to exude; and it was found that the thickened ink, technically termed "gatherings," adhered at first to the perforated surface between the perforations, and afterwards, when the film had arrived at a certain thickness, it was transferred bodily to the surface of the inking-roller. These experiments led to the adoption of the following inking apparatus:—

The short cylinder P, Figs. 513 and 514, containing the supply of ink, is fitted with a piston, the rod of which is a screw that projects below the cylinder, as shown in Fig. 513. The upper end of the cylinder expands into a horizontal rectangular tray, rather larger in size than the plate to be inked; and this tray is covered with a flat plate of steel, perforated with a number of small holes. The piston is slowly raised by the screwed piston-rod and the bevil-wheels Q, and ratchet-wheel R. In order to charge the cylinder with ink, the piston is lowered, and the perforated top plate removed for filling in the ink; and on replacing the top the piston is raised until the ink exudes through the perforations in the top plate, the lowering and raising of the piston being effected by hand by a winch upon the spindle of the ratchet-wheel R. The supply of ink during the working of the machine is kept up by the lever T from the cam-shaft, Fig. 514, acting on the ratchet-wheel R, a small but sufficient quantity of ink being in this way forced up through the perforated surface for every plate inked by the inking-roller C.

The inking-roller C, shown enlarged in Figs. 516, 517, and 518, is formed of a number of discs of woollen cloth, screwed tightly together upon a spindle and finished in the lathe. It is worked to and fro continually without intermission by the rack and sector B. This rack slides on a cylindrical rod D, which allows the frame E, carrying the roller, to be raised and lowered sufficiently to cause the inking-roller either to apply ink to the engraved plate on the polygon A above, as shown in Figs. 516 and 517, or to descend and roll on the inking-table P below, for obtaining a fresh supply of ink, as shown in Fig. 519. The roller is held up for inking the polygon by the weighted lever G, having an adjustable weight; and on the pressure of this weight being removed at the proper moment by a cam, the roller C drops and rolls upon the ink-table P with its

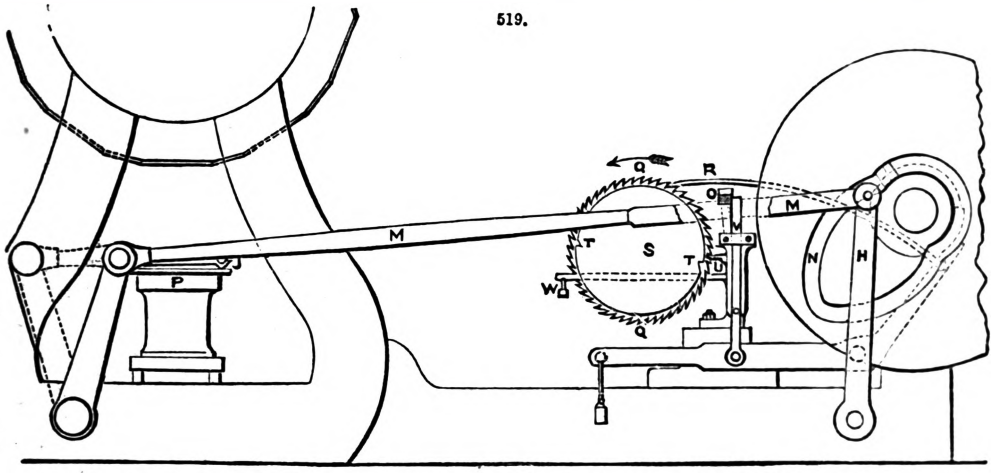
own weight, and that of the frame E, as shown in Fig. 516. It thus takes up a fresh supply of ink, while the polygon is turned through one-tenth of a revolution so as to bring the next engraved plate round into position, ready to be inked when the inking-roller is raised again by the lever G.

516. 517. 518.




As the ink is transferred from the perforated inking-table P to the inking-roller C in a series of dots through the holes in the inking-table, the engraved plates would be inked in a similar and therefore imperfect manner; but this is prevented by the application of the two small distributing-

519.




rollers I I, which are pressed in contact with the inking-roller by springs. One of these distributing-rollers simply revolves in contact with the inking-roller; but the other has on one of its bearings a screw, which gives it an end-traversing motion in addition to the rotary motion; and thus the ink coming to the roller in dots is equalized over its entire surface, and the inking of the engraved plates is rendered uniform.

The occasional removal of the thickened ink from the surface of the inking-table P is provided for by the arrangement shown in Fig. 519. The ink-scraper J is shown in the position when out of action, and H is the lever and M the connecting-rod for communicating the required motion to it from the cam N. On the scraper beginning to move across the inking-table P from the position shown at J in the drawing, a small cam at each end causes it to rise and so to pass clear over the table without scraping; while in the return motion the scraper descends into contact with the table, and pushes before it the thickened ink, which falls into a trough placed to receive it.

If the scraping were to be performed once for every impression printed, then it would only be required to allow the cam-roller at the end of the lever H to remain continually in the groove of the cam N. But as it is required that the scraping should be performed only occasionally, or once for every thirty-six impressions or revolutions of the cam-shaft, the following arrangement is adopted. At O is a latch, which so long as it is not raised holds the connecting-rod M pushed outwards laterally, so that the cam-roller is out of the cam-groove N. The ratchet-wheel Q has seventy-two teeth, and is carried forwards one tooth for every impression by the pawl R, which is actuated by the cam shown by the dotted line. Attached to the ratchet-wheel is a disc S, having only two notches T T in its circumference; and U is a rocking-frame, rocking on a pin at its lower end, and having on the upper part a projecting finger, which is caused by the weight W to press continually against the edge of the disc S. V is a bolt, worked up and down at each revolution of the cam-shaft by the same lever and cam that work the pawl R of the ratchet-wheel. The upper end of this bolt slides in the rocking-frame U; and so long as the finger is on the edge of the disc

S, the bolt V rises and falls just clear of the latch O, as shown in the drawing, so that it produces no action.

But once for every thirty-six impressions of the machine, the finger of the rocking-frame U enters one of the notches T in the disc, and the rocking-frame falling forwards, tilts the bolt V into the position indicated by the dotted line, when the next rising of the bolt lifts the latch O, as shown by the dotted line. The cam-roller is now thrown into the cam-groove N by the lateral pressure of the spring lever H, and the scraping of the inking-table P is performed once by the revolution of the cam N. At the end of the revolution the cam-roller is thrown out of the cam-groove N by the inclined stop X at the end of the groove, and is instantly held out by the dropping of the latch O; and before the bolt V again rises, the ratchet-wheel Q has been turned forwards one tooth, so that the finger of the rocking-frame U is again out of the notch T, and therefore the bolt V rises clear of the latch O, and ceases to lift it for the next thirty-six impressions.

BAR. Fr., *Barre;* Ger., *Stab;* Ital., *Scanno, Banco di rend;* Span., *Barra.*

A bar is a piece of wood, metal, or other solid matter, long in proportion to its diameter or width. A bank of sand, gravel, or other matter forming a shoal at the mouth of a river or harbour, obstructing entrance or rendering it difficult, is called a bar.

The term is also applied to an ingot, lump, or wedge of metal from the mines, run in a mould and unwrought.

BARBETTE. Fr., *Barbette;* Ger., *Geschutzbank, Pritsche;* Ital., *Barba, Parapetto a barba, Artiglieria in barba;* Span., *Barbetta.*

See Ordnance.

BARGE-BOARD. Fr., *Flache dosse;* Ger., *Schwarte, Schillstück;* Ital., *Fasciame d'aggetto del tetto;* Span., *Guarda Malletas.*

A barge-board, or verge-board, is a board, more or less ornamental, attached to the gable ends of a roof, chiefly in old English houses, to hide the ends of the horizontal timbers, and to protect from the weather the under-side of the *barge-course*, which is usually boarded or plastered.

BARGE-COUPLES. Fr., *Chevron extérieur;* Ger., *Aussere Sparren;* Ital., *Puntoni che aggettono.*

Barge-couples are the rafters placed under the *barge-course*, which serve as grounds for the *barge-boards*, and carry the plastering or boarding of the soffits.

BARGE-COURSE. Fr., *Battellement;* Ger., *Traufziegelreihe;* Ital., *Filare d'aggetto del tetto;* Span., *Boquillas.*

The barge-course is that part of the tiling or slating of a roof which projects over the gable of a building. The term is also applied, when there is no projection, to a coping of stone or brick laid above the tiling or slating along the sloping sides of the gable. A fillet of cement is usually run along the inside, to cover the junction between it and the slating.

BARLEY-DRESSING MACHINE. Fr., *Machine à préparer l'orge;* Ger., *Maschine zum Zurichten der Gerste;* Ital., *Macchina a preparare l'orzo.*

Figs. 520, 521, represent a machine, designed by J. T. Poyser, for screening and dressing barley and removing the broken grains. The barley to be dressed is placed in the hopper X,

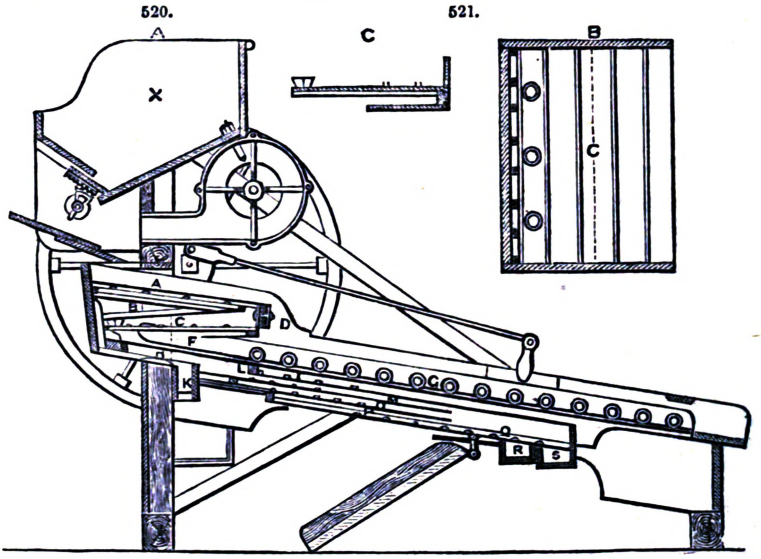



Fig. 520; this hopper has an opening at the bottom provided with a slide, by which the amount of grain allowed to pass through can be regulated. In falling from the hopper, the grain is subjected to the blast of a fan, which removes the dust, smut, &c. The grain is received on an inclined board which delivers it on to the screen A; this screen is mounted in a frame, which has a rapid reciprocating motion imparted to it in an inclined direction, by being coupled by rods to a crank on a transverse shaft.

The grain is delivered on to the screen A, and any beans, peas, stones, &c., which may be mixed with it, pass over this screen and down on to a second screen C, over which they also pass in

a passage leading to the shoot K, where they are delivered. The shoot K is provided with an inclined perforated plate, which effects the separation of any stray corn which may have passed over the screens, A and C, with the refuse, the latter passing over the inclined perforated plate in the shoot, and being delivered on one side of the machine, whilst the grain passes through the plate and is delivered on the opposite side. The refuse which passes over the plate C is prevented from clogging the passages leading from the lower end of that plate to the spout K, by causing it to separate and pass on either side of circular blocks of wood placed opposite these passages and between the plates C and B. These blocks are shown in the plan and section of the perforated plate C, Figs. 520 and 521, and they not only serve the purpose we have mentioned, but, by retarding the progress of the refuse, cause the corn to be more effectually separated from it.

The screen-plates, A and C, have shallow transverse bars on their upper sides, and they are perforated with openings of sufficient size to permit of the passage through them of the grains of barley. The grain which passes through the screens is received by the plain zinc trays, B and E, and by them delivered on to the perforated plate F. This plate is provided with transverse bars on its upper side, and over it the grain passes down to the screen G, which is without transverse bars, but which is subjected to the action of a series of rollers. A portion of the broken and damaged corn and refuse matters of a smaller size than the grains of barley pass through the plate F and fall upon the inclined board H, down which they are led to the perforated plate L, which is provided with transverse bars. The damaged corn and small refuse matters fall through this plate on to the plate N, which leads them to the perforated and ribbed plate O, through which they fall on to the last perforated screen P, any refuse passing through this screen being delivered beneath the machine

Any good barley which may have been delivered through the screen F, and over the plate H, to the screen L, passes over that screen to the plain plate M, which carries it forward and delivers it on to the screen Q. This screen also receives any good grain which may have been separated from the light and broken grain during its passage over the inclined plate N, and the perforated plates O and P. The best barley passes over the perforated plate Q, into the spout S, whilst that which passes through the perforated plate is received by a plain plate, which conducts it to the spout R, by which it is delivered at the side of the machine as a second sample.

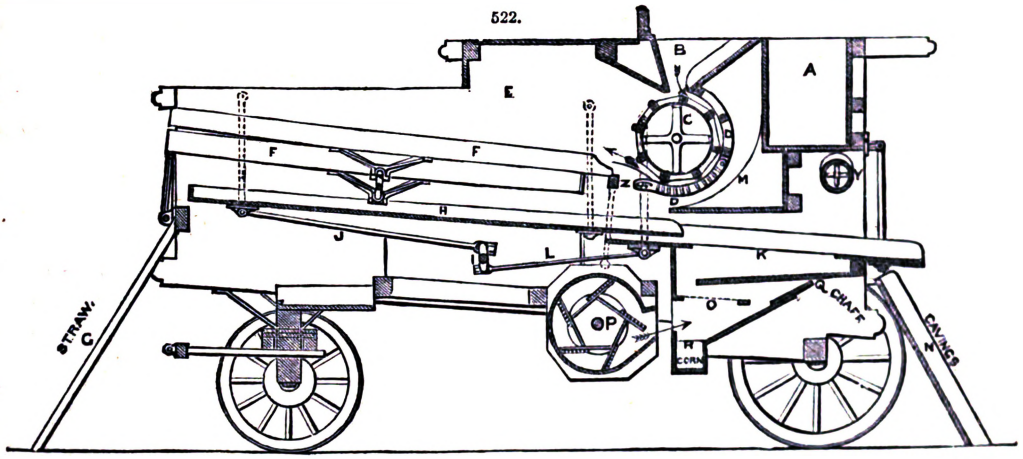
We must now return to the grain which, passing over the perforated plate F, is delivered to that marked G. Whilst passing over this latter screen, it is subjected to the action of a series of small wooden rollers covered with india-rubber, the axes of these rollers being carried in slotted holes in a pair of side-rails in such a manner that the rollers are free to rise and allow the grain to pass beneath them. The side-rails just mentioned are supported by brackets, which pass through long slots in the sides of the movable frame carrying the screens, and are bolted to the main frames of the machine, so that the rollers have no reciprocating motion, the screen-plate G passing to and fro under them.

BARN MACHINERY. Fr., *Machines employées dans les fermes;* Ger., *Landwirth schaftliche Apparate;* Ital., *Macchine impiegate nelle cascine.*

Barn machinery may be divided into the following classes,—threshing and dressing apparatus for grain; mills and flour-dressing apparatus; corn-crushing, straw-chopping, and root-cutting implements.

Fig. 522 shows a longitudinal section of a Portable Threshing Machine. The sheaves of corn having been unbound, are passed to the feeder, who stands in the dickey A, and shakes the straw

522.



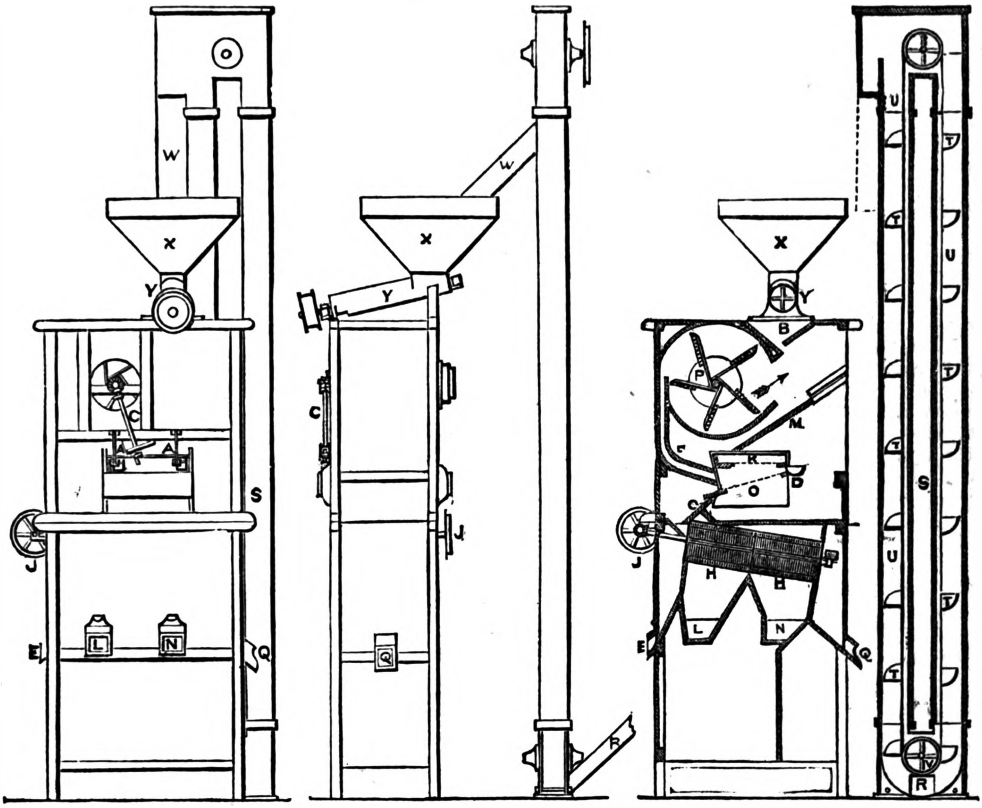

loose into the mouth of the machine B; here it meets the drum C revolving at a high velocity, which carries it over the concave or breastwork D, beating out the grain from the ears. The grain falls through the breastwork D, while the straw is thrown off into the chamber E, whence it is taken forward by the shakers F F, and thrown over the straw-board G. The shakers F by their motion also separate the straw, and allow any grain that may have been thrown off from the drum with the straw to fall on to the shock-board or shogging-board H, whence, by means of the motion given to the shogging-board from the crank-shaft I, through the connecting-rod J, it is passed down to the riddle-board K, to which an opposite motion is communicated by the other connecting-rod L from an opposite crank on the shaft I, the two boards, H and K, advancing to each other or

receding simultaneously, both being suspended by links to the framing, and swinging loosely between the sides of the machine.

The grain that passes through the breastwork D is guided by the bent plate M, so as to fall upon the top end of the riddle-board K. In working the machine, many heads and short straws fall from the breastwork and shakers, and a coarse riddle or perforated plate is put on the top of the riddle-board K to take them out from the corn; these "cavings," as they are called, pass over the end of the board K, and fall down the caving-board N. The corn and all smaller substances, chaff, and so on, pass through the top riddle, and down an inclined board on to a second riddle O, of a finer mesh or perforation; here they meet a blast of air from the fan or blower P, which blows away the chaff through the opening Q, while the grain which is heavier falls into the spout R.

The grain is thence carried away by the elevator S, Figs. 523, 525. This is composed of a number of tins or cans T fixed on a belt U, which works over two pulleys V V, one at the top and

523. 524. 525.




the other at the bottom. The spout R of the threshing machine delivers the corn into the bottom shoe of the elevator: the cans T, being carried round by power applied through a belt to the spindle of the top pulley, take up the grain, and in turning over the upper pulley discharge it into the spout W, Fig. 524, which forms a hopper for it; thence it passes to the next process.

The drum C, Fig. 522, of the threshing machine, is shown in four modifications in Figs. 526 to 533. That shown in Fig. 526 is composed of rings A, supported by arms B; on these are fixed the wood-beaters C shod with iron, having a filling-piece D, also plated with iron, inserted in front of each beater, to prevent the straw being carried round with the drum instead of being passed away. Fig. 527 shows a close drum made of plate arms B and angle-iron, with angle-iron beaters C having wood supports. Fig. 528 represents a drum now in use, having wood-beaters C, over which wires E are strained; on the top of these are bolted the beater-plates F, which are grooved in the face, as shown in Fig. 529, the object of the grooves being to allow the grain to pass into them, and prevent it from being broken, as was the case with plain straight beaters.

The breastwork D, Fig. 522, is shown in detail in Fig. 528. It consists of a frame made in two portions, the upper part from G to H being of wood, and the lower part from H to I of iron; these are carried by iron rods passing across the machine at the three points G, H, and I, which afford the means of adjusting the position of the breastwork by means of screw adjusting-pieces at the sides of the machine, so as to bring it nearer to or farther from the drum, as may be required. The adjustments at G and H being horizontal sliding adjustments, and that at I vertical, a slot J is required at the outer extremity of the frame, in which the rod I works. The distance between the breastwork and drum is gradually contracted from the top towards the bottom, to ensure the whole of the straw being exposed to the action of the drum; this distance is sometimes about 1½ in. at the top, and reduced to only ¼ in. at the bottom, but the adjustment is dependent upon the state of the grain. The upper half of the breastwork is furnished with transverse strips or ribs of wrought

iron K, about 1½ in. wide by ¼ or ⅜ in. thick, let in to the sides of the framework; these are perforated with holes, through which a set of wires are passed, forming a concave grating to prevent the straw from getting through. The lower half of the breastwork is a frame of iron bars D, also

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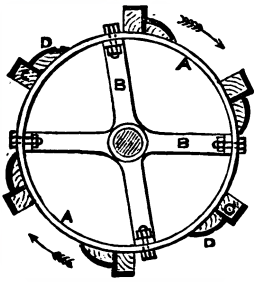


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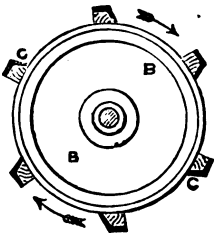


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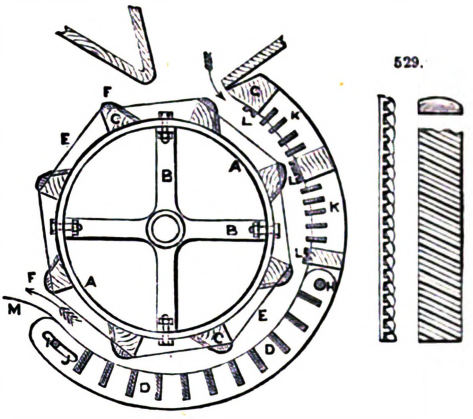


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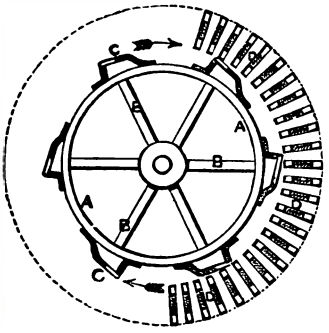


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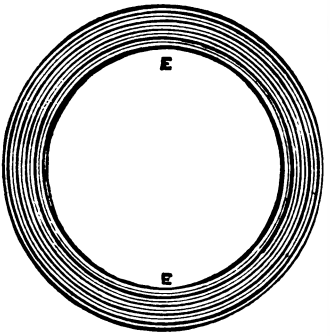


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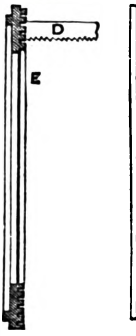


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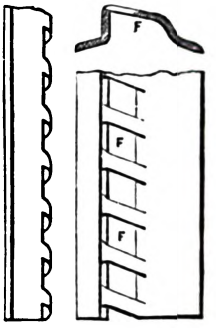
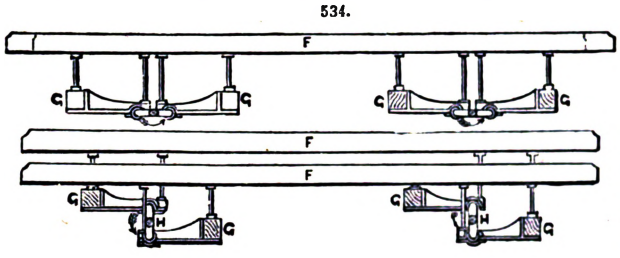



covered with wire. Strips of bar-iron L rolled with one or two longitudinal grooves are fastened on the wooden frame of the breastwork, projecting slightly to prevent the straw from passing too quickly without being thoroughly threshed. The straw is guided from the breastwork to the shakers by the plate M.

Another plan of breastwork, invented by Barrett, Exall, and Andrewes, is shown in Fig. 530, formed by a series of flat bars D, held in their places by the sides of the machine in which slots are cast; the bars are all moved together, to or from the drum A, by a worm-plate E, Figs. 531, 532, in which their ends rest, and are thus adjusted to the required distance from the drum. The plan of drum adopted in connection with this breastwork is also worth notice, as being new, simple, and efficacious. Three or more sets of arms B are keyed on the spindle, each set being completed by a loop A on the outside, on which are fixed the wrought-iron beater-plates C, of the form shown in Fig. 530. The beater-plates are made of flat iron, rolled or pressed into the shape, with the spaces F cut in, as shown in Fig. 533, so that any grain they may collect may pass into the drum until it can find its way again to the breastwork D. This beater seems to be more perfect in its mechanical construction than the others, where wood and iron are used together.

Figs. 534 to 539 show three modifications of the straw-shaker F, Fig. 522. Figs. 534, 535, represent side-elevations and end-elevations of the two positions of a "rail-shaker," which is made of a

534.

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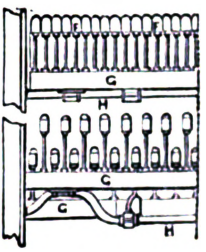
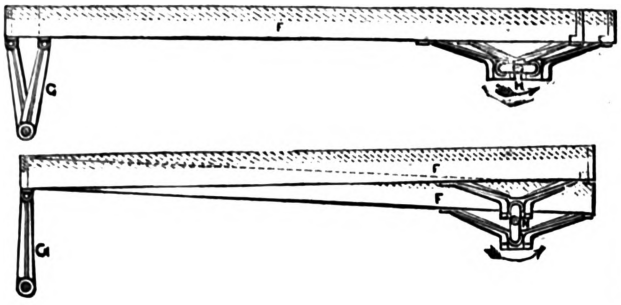



number of rails or bars F F attached alternately to two frames G G, actuated at both ends by the two crank-shafts H; the shafts H are also coupled together by means of cranks on their outer ends

and coupling-rods. Figs. 536, 537, show a "box-shaker," consisting of a set of boxes F F, covered with perforated sheet iron, or with sloping strips of thin hoop-iron, as shown dotted; the boxes

536.

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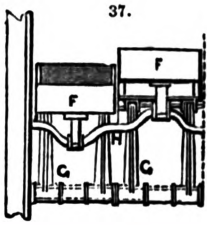
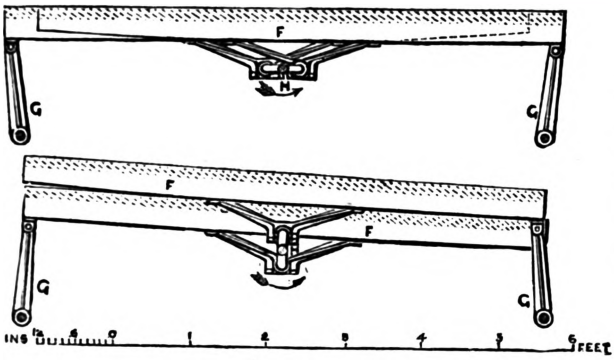


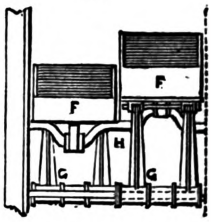

are carried at one end by radius-links G, and the other ends are attached to double cranks on the shaft H, which give the alternating movement, the boxes thus rising and falling to receive or deliver the straw the one to the other, and the rotary motion of the cranks also carrying it forwards, as in the former case.

An improvement upon these two methods is shown in Figs. 538, 539. The great fault of the rail-shaker consists in its passing so many straws through; while the objection to the box-shaker

538.




539.




is, that any grain that has been thrown by the drum to the outer end of the chamber E, Fig. 522, is carried along with the straw over the end of the shaker, in consequence of the vertical motion of the crank being reduced at that point, and becoming only a horizontal or longitudinal motion at the end. To obviate these defects, the new shaker, Figs. 538, 539, was invented by James Good. The principle on which this is constructed differs from that of the ordinary box-shaker, Figs. 536, 537, in this respect, that while the latter has the crank-bearings at the same end for all the boxes and the radius-links G at the other end, in Good's shaker the boxes are supported by the links alternately at opposite ends, the crank-shaft H being thus between the links G; or, in other words, the crank-shaft H may be said to be moved to the middle of the length of the boxes, and half of the boxes to be then turned round end for end. Thus, while the ends that are attached to the links close to the drum rise only so much as is due to the vibration of the rocking-links, the ends of the other boxes have a considerable lift imparted to them from the crank; in the centre of the length of the boxes, just over the crank-shaft H, the lift and throw are the same as in the most effective part of the old shaker; and again at the outer end the straw is tossed by the loose ends of the boxes, while only a passing or horizontal motion is given by the others. This is known as the "cross-shaker," owing to the boxes moving crosswise, or alternately up and down.

There is another shaker, invented by T. and H. Brinsmead, the features of which are different from those of every other. Immediately over an inclined plane of wood, and sufficiently above it to allow them to revolve without touching it, are placed transversely, and therefore horizontally, a series of triangular prisms of wood, armed at their edges with curved iron teeth, so arranged that, as the prisms revolve, the teeth of each pass between those of the two adjoining prisms. The prisms being made all to revolve simultaneously in one direction, either by cranks on the ends of the spindles coupled together by one rod, or by a train of wheels, the straw which falls on those at the lower end of the plane is tossed and carried upwards by the action of the teeth as they rise, which also, as they pass down again between the teeth of the prism next above, deliver the straw on to these last, and sweep down to the bottom of the plane the corn and any short straw that has fallen through. At the bottom of the plane is a curved wire-netting, through which the corn readily passes, but which stops the passage of any straw; and the revolving teeth of the lowest prism rake up the straw again as it accumulates, and toss it upwards and onwards as at first.

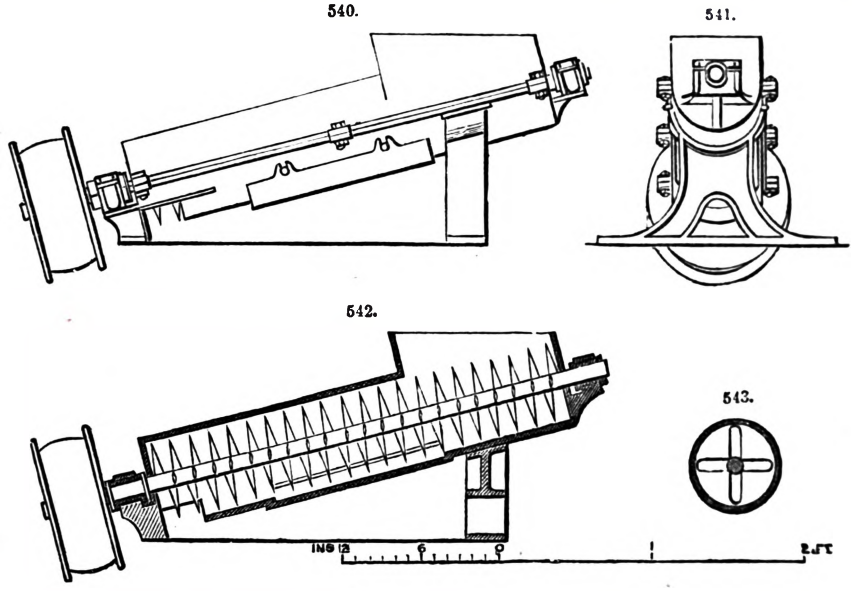
In the shaker shown in Fig. 522 there are five boxes, two working on links at the end of the machine, and the three alternate boxes vibrating on links at the end nearest the drum; the inner

ends of the latter are prolonged, to allow for the throw of the crank, and are attached by means of an angle-iron to a cross-bar Z, extending across the machine, and carried by two links outside the framing, one on each side, as shown dotted, thus avoiding any links inside the machine.

The slogging-board H and the riddle-board K, Fig. 522, were originally in one length; and the vibration then caused by this single piece moving backwards and forwards impeded the introduction of portable machines. They were, however, afterwards parted into two lengths, and in the present machine the motion of the two boards in opposite directions neutralizes the disturbing effect of the reciprocating weight of both.

The elevator S, Figs. 523, 525, has been already described in a form generally in use. Another kind of elevator also in use is formed of sheet iron bent round a spindle in a spiral form, working in a trough curved to the radius of the outside of the worm, and touching it, thus winding the corn, &c., that falls into the trough, by means of the worm, up the spout; but as it must necessarily be kept at only a slight inclination, this elevator is not so general in its application as that previously described, nor nearly so cheap in construction.

From the spout W, Figs. 523, 524, the grain is delivered into the hopper X of the corn-dressing machine, and thence into the barley-horner Y, which is shown more fully in Figs. 540 to 543. It is here subjected to the action of a number of knives fixed on a spindle, which loosen the




husks or whites of the wheat and cut the ears or horns off the barley. Independently of the inclined position of the barley-horner, the grain is kept in motion by the "set" of the knives, which are in a spiral form. Motion is given to the spindle by a pulley fixed on the end.

The grain and loose ears pass from the barley-horner into the mouth B of the dressing machine, and are met in their descent by a current of air from the fan or blower P, which clears the grain of all chaff and ears that may have been left in it; the grain falling upon the inclined board M is conducted to the riddle K, which is carried upon the links A A, Fig. 523, and has motion communicated to it by the crank at the end of the spindle C. Any stones or ears that may have got in are here taken out, and pass over the riddle K into the spout D, whence they are conducted into the delivery-spout E. The grain, on falling through the riddle, is caught by a fine wire-sieve O, through which all small seeds pass, and are carried also to the spout E. The grain passing over this sieve, is swept by a current of air taken from the back of the blower P by the passage F, by which it is effectually cleaned of any lighter seeds that may be too large to pass through the sieve, and also of any chaff that may have been loosened from the grain by the riddling. The board G carries the grain to the mouth of the revolving sieve or screen H, which receives a rotary motion from the wheels J. The small imperfect corn, or "light" corn, falls through the first meshes into the spout L; the mesh, being then altered and widened, allows the broken corn and a larger size, or "tail" corn, to fall through into the spout N; while nothing but the best corn can find its way to the spout Q. A simple apparatus is here fixed, consisting of a *weighing machine* with rods and bell-cranks, so arranged as to shut off the delivery and ring a bell when the scale falls. A bushel of corn weighs 60 lbs.; four bushels make a sack; and the weight of the sack itself being 7 lbs., 247 lbs. is therefore the weight to be put in the scale; the empty sack is held open to the spout Q by means of rods fixed on this scale of the machine. When the four bushels of corn are delivered, the scale falls, loosing the catch of the slide, which immediately shuts, and allows a bell that has hitherto rested upon the top of it to swing clear, and ring, thus calling the attendant to put a fresh sack on and reopen the slide.

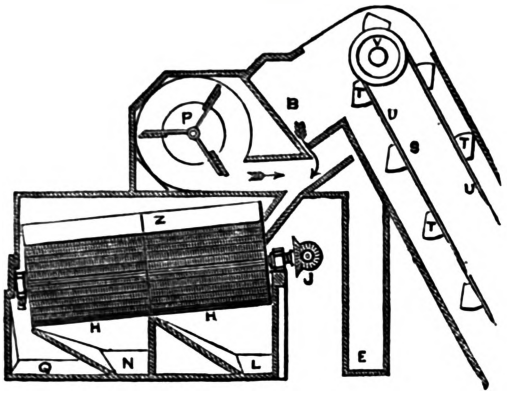
The whole process, from the time when the corn in the straw is fed to the threshing machine, Fig. 522, to the time when the grain, dressed and sorted for market, is sacked in half-quarter quantities from the spout Q, Fig. 524, is thus entirely self-acting; and in this time the following separations are made:—straw, cavings, chaff, seeds, light corn, tail-corn, best corn; besides dust, which must inevitably be mixed up with the straw at first, and which is blown away in the process.

The portable threshing machine is now so arranged as to combine the dressing and separating process with the threshing and winnowing in one machine.

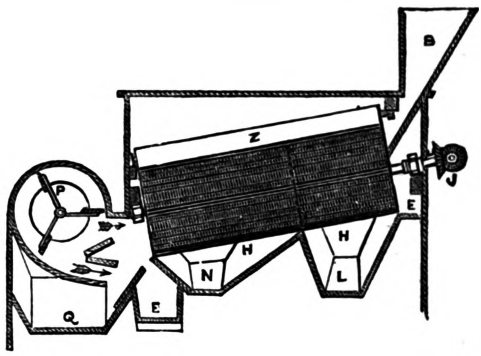
The riddle-boards K and O, Fig. 522, are divided longitudinally and vertically into two parts, as is also the blower or fan P, thus forming two distinct sets of blowers and riddles. The corn passing through the first set, arrives at the spout R, as before described, from which it is taken up by elevators, and passed into the hopper of a barley-horner Y, placed under the dickey A of the portable machine. It is thus passed to the other side of the machine, where it falls down in front of the second half of the divided blower, corresponding to the blower P in Fig. 524, upon the new or second set of riddles, corresponding to the riddles K and O in the same figure, down to a second spout corresponding to the spout R on the other side of the machine. It is here again taken up by another set of elevators, and discharged into the hopper B of the separator, Figs. 544, 545, passing through the revolving screen H, and being delivered as before, the light corn by the spout L, the tail at N, the best at Q, and the seeds and dirt at E E.

In this separator a blower P is fixed, either above the machine and screen-case H, to blow all chaff and seeds out before passing into the screen, as in Fig. 544, or at the end, as in Fig. 545. In

544.

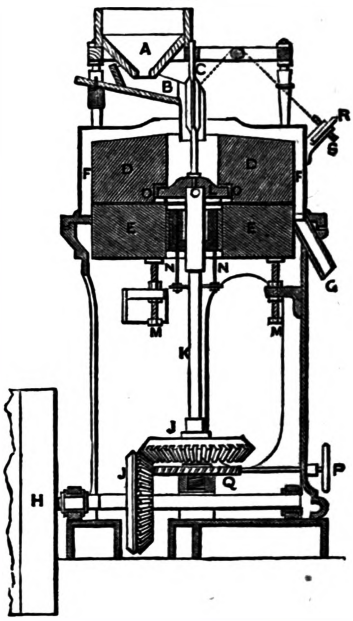



545.




the latter plan, shown in Fig. 545, the corn is subjected to the action of the blast while on the screen and in falling from it. The arrangement, however, shown in Fig. 544, introduced by Clayton, Shuttleworth, and Co., is found to be an improvement, and has been adopted in place of the other arrangement. The plan first tried was to blow up the screen; then under; then up and under; but in the last plan the chaff and light corn are blown out before reaching the revolving-screen H, consequently power is saved; and experience shows that a better sample is obtained by this arrangement. In both the plans, shown in Figs. 544 and 545, brushes Z Z are fixed above the revolving screens H to keep the wires clear. The separating apparatus is fixed on the side of the portable threshing machine, and the grain is delivered in the same separations as enumerated previously.

546.




The action of threshing is still supposed by many to be a continuous series of blows; by others to consist of rubbing between the beaters and the surface of the breast-work; and by others, again, to be the combination of the two actions.

In the present machines in this country the straw is fed across the drum, so as to allow the drum to "boult" it, or carry it through without twisting or breaking the straw, which is with many farmers a serious consideration. In the old and in the present American machines, the straw is broken up by means of pegs on the drum and breastwork; but as the Royal Agricultural Society take notice of the state of the straw, whether it is broken or not, it has become an object to preserve it.

With regard to the riddles, the top riddle-plate K, Fig. 522, is coarse in the openings, to allow the corn to pass through freely; the second riddle O is finer; and in the combined machines with the split-blower and riddles, the third and fourth riddles, corresponding to K and O in Fig. 525, are each finer than the one before it. The riddles are sometimes made of wire netting, and sometimes of wood perforated at an inclination; but more frequently of punched sheet iron.

The next process through which the grain has to pass is grinding, breaking, or kibbling, as it is called, according to the degree of fineness of the meal required. Several methods have been proposed, but the old plan of one stone revolving above another which is fixed is still found as good and economical as any. Fig. 546 shows a vertical section of a portable corn-

mill constructed on this plan. The corn being fed into the hopper A, is shaken down the spout B by the damsel C, working against the spout, into the eye of the upper or running stone D, whence it gets into the furrows of the two stones D and E, passing out from them as meal into the casing F, from which it is carried off by the spout G. Motion is given to the runner D from the pulleys H through the shaft I by means of the mitre-wheels J to the vertical spindle K; at the top of the spindle are two studs, on which rides the casting L, which in its turn carries the running-stone D by the two steps O. The damsel C being fastened in the casting L, receives motion from it. The bed-stone E is adjusted by the set screws M M; and the screwed wedges N keep the wood-packing against the spindle K. The coarseness or fineness of the meal is regulated by the hand-wheel P working a worm-gearing in the worm-wheel Q, which is keyed on the top of a brass bush resting in an outer bush or seating, with a square thread cut in the two bushes; thus, by turning the wheel P, the worm-wheel Q causes the inner bush to turn in its seat on the thread, thereby raising or lowering the spindle K, and with it the upper stone D. The hand-wheel R acts as a nut upon the screw S, raising or lowering the spout or shoe B, and thus diminishing or increasing the feed to the stones. The object of these mills on farms is to break wheat, barley, oats, &c., into meal for food for man and beast; it is only worked occasionally, and therefore the arrangements for cooling the flour and meal are not required.

The Flour-dressing Machine consists of a case containing an inclined cylinder of wire gauze of various degrees of fineness; on a spindle passing along the centre of this cylinder are fixed by means of arms keyed on it a set of brushes, which revolve at about 300 to 500 revolutions per minute. The meal or broken corn is passed into one end of the cylinder, and the fine flour falls at once through the wire into the first compartment; by means of the brushes and alterations in the gauge of the wire five or six separations are made.

The smaller implements forming part of the barn works are of modern introduction, and have been brought forward by science to assist the practical agriculturist. Those in most general use are—

*Linseed and Corn crushers; Chaff-cutters, or Straw-choppers; Turnip-cutters and Root-cutters; Gorse crushers or cutters; Oilcake crushers or breakers.*

The Linseed and Corn crushers have been introduced to effect a saving in the quantity of corn necessary for animals, as the crushing or bruising ensures the whole of the nutriment contained in the grain being rendered available, instead of the animal swallowing the food without properly masticating it. The process is simple; the grain is merely passed between plain or grooved rollers, crushing, not grinding, being the object; the bulk is thereby increased at least one-third, and its nutritive power in the same ratio. This idea is really of very old date, though only of recent adoption, having been recommended by Hartlib in 1650.

The Chaff-cutters are made with two or more knives shaped concave or convex towards the edge, and fixed on a shaft carrying a fly-wheel. A feed-motion is attached to bring the straw or hay up to the knives, the straw being placed in a box, and the knives working across the end of the box and close against it. The length of the cut is variable, and may be altered from about ¼ inch to 3 inches by adjusting the amount of the feed.

Turnip-cutters are discs, arms, or plates of metal with knives or cutters to pare or slice turnips or other roots, which lie against the knives by their own weight; the roots are cut in slices for cattle, and in strips for sheep, cross-cutters being then introduced.

Gorse-crushers are made with toothed rollers to bruise the gorse for feeding beasts, which eat it with avidity; it is crushed by the machine to a harmless pulp, and cut into short lengths.

Oilcake-breakers are made with toothed rollers, by which the cake is taken hold of and broken, the cut being adjusted by set screws, so as to regulate the degree of fineness required, according as the cake is being broken for cattle or sheep; the dust from the cake passes through a grating.

The results of experience with the several machines have led to the adoption of the following speeds of working as the most eligible for the purpose:—

The speed of the drum of the threshing machine is found to be best at about 5000 ft. of the circumference a-minute.

The straw-shaker should pass the straw at the rate of 75 to 80 ft. a-minute.

The shogging-board and riddle-board should be worked at about 200 revolutions of the crank a-minute.

The blowers should run at about 2000 ft. of the circumference a-minute.

The barley-horner spindle should make 400 to 500 revolutions a-minute.

The elevators should work at 100 or 150 ft. a-minute, but the rate is dependent upon the quantity to be taken up, and it may sometimes be found necessary to quicken the speed.

The best speed of a 3-ft. stone for a mill similar to the one described is found to be about 140 to 150 revolutions a-minute, or about 1400 ft. a-minute of the circumference, instead of 1550 to 1600 ft. a-minute, as given by the ordinary rule, the lower speed giving the greatest quantity of work done for the least amount of power expended.

The smaller machines are not so delicate in their operations, and are more dependent upon the kind of stuff they are fed with and the state it is in, and therefore do not allow of any fixed rule.

The growth of the threshing machine having been traced from the simple threshing drum and breastwork to the complete machines now in use, an interesting experiment may be mentioned, which was tried at the meeting of the Yorkshire Agricultural Society, at Ripon, in 1854. to ascertain the power consumed by the several parts of the machine.

A combined fixed machine with a dressing apparatus as described, required 6·15 horse-power to drive it when at work, and 1·77 horse-power when empty, leaving 4·38 horse-power available for doing the work. This machine threshed 200 sheaves of wheat in 13 80 minutes, and the power expended was accordingly 6·15 horse-power for 13·80 minutes, equivalent to 84·87 horse-power for one minute: or, multiplying by 33000 and dividing by 200, the power expended was—

14004 units of work to thresh 1 sheaf of wheat

(one unit of work being one pound weight raised one foot high). The 1·77 horse-power required to drive the machine, when empty, was divided as under:—

| | Horse-power. |
|---|---|
| Dressing Machine .. .. .. .. .. .. .. | ·37 |
| Elevator .. .. .. .. .. .. .. .. .. | ·11 |
| Shaker and Riddle .. .. .. .. .. .. | ·28 |
| Blower .. .. .. .. .. .. .. .. .. | ·20 |
| Drum and Shafting .. .. .. .. .. .. | ·81 |
| Total .. .. .. .. .. | 1·77 |

A similar machine required 4·23 horse-power to drive it when at work, and 2·70 horse-power when empty, leaving 1 53 horse-power available for doing the work. This machine threshed 200 sheaves of wheat in 22·68 minutes, and the power expended was accordingly 4·23 horse-power for 22·68 minutes, equivalent to 95·94 horse-power for one minute; or, multiplying by 33000, and dividing by 200, the power expended was—

15830 units of work to thresh 1 sheaf of wheat.

The 2·70 horse-power required to drive the machine when empty was divided as under:—

| | Horse-power. |
|---|---|
| Dressing Machine.. .. .. .. .. .. .. | ·34 |
| Elevator .. .. .. .. .. .. .. .. .. | ·28 |
| Shockboard and Pulley .. .. .. .. .. | ·39 |
| Blower and Drum .. .. .. .. .. .. | 1·46 |
| Main Shaft and Shaker .. .. .. .. .. | ·23 |
| Total .. .. .. .. .. | 2·70 |

The power expended in threshing 1 sheaf of wheat has been gradually increased from about 6000 units in the earlier machines by the additions in successive years of further apparatus to render the process more complete, several operations being combined in the one machine.

Taking a similar basis of calculation, the power required to work the portable corn-mills and smaller barn implements, as reduced from the average results of the trials at the show of the Royal Agricultural Society in 1855, is as follows:—

| | | | |
|---|---|---|---|
| Portable Corn-mills, | about 9000 | units | to grind 1 lb. of corn. |
| Corn-crushers, | „ 3600 | „ | to crush 1 lb. of linseed or oats. |
| Chaff-cutters, | „ 2200 | „ | to cut 1 lb. of chaff. |
| Turnip-cutters, | „ 150 | „ | to cut 1 lb. of turnips. |
| Oilcake-breakers, | „ 180 | „ | to break 1 lb. of cake for cattle. |
| | „ 350 | „ | to break 1 lb. of cake for sheep. |

A trial of threshing machines took place in Kent, in April, 1856, when one machine threshed, without finishing, about 21¼ quarters of wheat with 350 lbs. of coal in 3½ hours; while another machine, having extra machinery attached to it for finishing, threshed and finished for market in the same time about 25½ quarters with 563 lbs. of coal, and that under disadvantage, owing to very high wind, and the windy side of the stack having fallen by lot to it. A stack of barley was threshed and finished by the second machine in 7¾ hours, including stoppages amounting to 1¼ hour, making the actual time 6½ hours; in this time the machine was found to have yielded 73 quarters of barley, or at the rate of 11·23 quarters per hour; the engine employed was of 7 horse-power.—(Taken from a paper by W. Waller, given in 'Proc. Inst. of Mec. Eng.,' 1856.)

BARKER'S MILL. Fr., *Roue hydraulique de Barker;* Ger., *Segner's Wasserrad;* Ital., *Mulinello idraulico a reazione;* Span., *Molino de Barker.*

The simplest form of reaction water-wheel is that of Barker's Mill, Fig. 547. Water-wheels are divided into groups according to the form of the part which receives immediately the action of the water.

The following synoptical Table exhibits at one view the different kinds of water-wheels and machines of rotation:—

- Water-wheels and machines of rotation.
  - Vertical ..
    - with floats .. — plane, in a water-course (rectilinear. circular.); in an indefinite fluid. — curved. Wheels of Poncelet.
    - with buckets receiving the water — at summit. Overshot wheels. — below summit. Breast or undershot.
  - Horizontal ..
    - with floats .. — struck by an isolated vein. — placed in a cylinder. Tub-wheels. — outside cylinder. Turbines of Fourneyron.
    - with conduits. Turbines of Burdin, of Boyden, of Francis.
    - reaction. Barker's Mill. Wheels of Segner, of Euler.

The water-mill, shown in Fig. 547, invented by Barker, performed the operation of grinding corn without either wheel or trundle; A is a pipe or channel that brings water from a reservoir to the upright tube B.

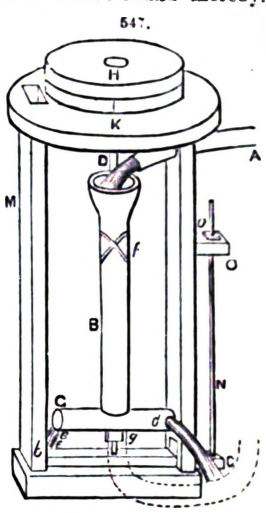
The water runs down the tube, and thence into the horizontal trunk C, which has equal arms; and, lastly, runs out through holes at *d* and *e*, opening on contrary sides near the ends of those arms. These orifices, *d*, *e*, have sliders fitted to them, so that their magnitude may be increased or diminished at pleasure.

The upright spindle D is fixed in the bottom of the trunk, and screwed to it below by the nut

$g$, and is fixed into the trunk by two cross-bars at $f$; so that, if the tube B and trunk C be turned round, the spindle D will be turned also.

The top of the spindle goes square into the rynd of the upper mill-stone H, as in common mills; and as the trunk, tube, and spindle turn round, the mill-stone is turned round thereby. The lower or quiescent mill-stone is represented by I, and K is the floor on which it rests, in which is the hole L to let the meal run through, and fall down into a trough which may be about M. The hoop or case that goes round the mill-stone rests on the floor K, and supports the hopper in the common way. The lower end of the spindle turns in a hole in the bridge-tree G F, which supports the mill-stone, tube, spindle, and trunk. This tree is movable on a pin at $h$, and its other end is supported by an iron rod N fixed into it, the top of the rod going through the first bracket O, and having a screw-nut $o$ upon it, above the bracket. By turning this nut forward or backward the mill-stone is raised or lowered at pleasure.

547.




Whilst the tube B is kept full of water from the pipe A, and the water continues to run out from the ends of the trunk, the upper mill-stone H, together with the trunk, tube, and spindle, turn round. But if the holes in the trunk were stopped, no motion would ensue, even though the tube and trunk were full of water. For, if there were no hole in the trunk, the pressure of the water would be equal against all parts of its sides within. But when the water has free egress through the holes, its pressure there is entirely removed: and the pressure against the parts of the sides which are opposite to the holes turns the machine.

James Rumsey improved this machine, by conveying the water from the reservoir, not by a pipe, as A D B, in great part of which the spindle turns, but by a pipe which descends from A, without the frame L N, till it reaches as low or lower than G, and then to be conveyed by a curvilinear neck and collar from G to $g$, where it enters the arms, as is shown by the dotted lines at the lower part of the figure.

Most of the authors who have attempted to lay down the theory of this mill have fallen into error. The most ingenious theory we have yet seen is by William Waring (given in the 'American Transactions,' vol. iii.), which, with some such corrections as appeared necessary to adapt his rules to practical purposes, is nearly as follows:

The first inquiry relates to the *magnitude of the pipe* which conveys the water from the reservoir to the centre of the horizontal tube $e$ $d$, at $g$. To this end, let A = the area of the orifice by which the water is admitted at $g$; $h$ = the perpendicular height of the surface of the water in the reservoir above $g$; $d$ = the vertical depth of any horizontal section of the pipe below the same surface; S = the surface or area of the horizontal section of the pipe, at the depth $d$. Then, since the areas in the several parts of the pipe should be inversely as the velocities, and the velocities are in the subduplicate ratio of the depths below the head, those areas must be inversely in the subduplicate ratio of the depths; consequently, $\frac{S}{A} = \frac{\sqrt{h}}{\sqrt{d}}$, and $S = A\sqrt{\frac{h}{d}}$. So that the pipe must have its bore increased from the level of $g$ upwards in the ratio of 1 to $\sqrt{\frac{h}{d}}$; and if a section in any part be less than would be assigned by this ratio, the water will be obstructed in its passage.

*Of the Initial Force with which the Machine commences its Motion.*—If we conceive the water pressing in the tube from $g$ towards $e$, previous to the opening of the aperture, there will manifestly be no motion occasioned, because the forces on the opposite sides of the tube balance each other, and the force against the end C is resisted by the fixed axle D$g$; or, if we consider both arms, it is balanced by the equal force acting upon the equal end at $d$ in an opposite direction. But if one of the apertures, as $d$ (its area being = $a$), is opened, the pressure upon that portion of the tube is taken away, and the equal and opposite pressure upon an equal portion of the contrary side of the tube, having now nothing to keep it in equilibrio, tends to move the arm C$g$ about the axis D$g$. In like manner, when the aperture $e$ (also = $a$) is opened, the pressure, which was previously counterbalanced by the opposite pressure on the orifice $e$, now exerts its tendency to produce a rotatory motion about the axis D$g$; so that, combining together the effects of both these unbalanced pressures, and considering that the pressure of water upon any point is proportional to the depth of that point below the upper surface of the fluid, we shall have $2\,a\,h\,w$ for the force which causes the rotatory motion to commence; the values of $a$ and $h$ being taken in feet, and $w$ representing 62½ lbs. avoirdupois, the weight of a cubic foot of water. But as the velocity of rotation increases, the pressure depending upon the relative velocities of the water and the sides of the tube diminishes, and consequently the power is diminished, notwithstanding what is gained by that which we now proceed to consider.

*The Centrifugal Force.*—This may be found in a similar manner to that which is adopted when considering the theory of the *centrifugal pump*. Thus, if, besides the preceding notation, we take $l$ for the length of each arm $g\,d$, $g\,e$, $t$ for the time of rotation, $g$ for 32⅛ ft., the measure of the force of gravity, and $\pi$ for 3·141593, since $a$ is the section of the flowing water at right angles to its motion, we shall have, by proceeding as in the article just referred to, $\frac{2\,\pi^2\,l^2}{g\,t^2}$ = the length of

a column of water, whose pressure is equal to the centrifugal force, or $\frac{4\pi^2 a w l^2}{g t^2} = 76{\cdot}70625 \frac{a l^2}{t^2}$ the weight of a column of water in lbs., which is equivalent to the centrifugal force of the fluid in both arms. And this is equivalent to the augmentation of power at the apertures, because fluids press equally in all directions.

*The inertia of the fluid* greatly counteracts the effects of the centrifugal force. The inertia of the rotatory tube with the contained fluid would not continue to resist the moving power after the velocity became uniform, were the same fluid retained in it as was in it when the motion was first imparted; but as this passes off, and there is a continual succession of new matter acquiring a motion in the direction of the rotatory, there must be a constant reaction against the sides of the tube equal to the communicating force. Now this reaction is very different from that of a fluid confined in the tube when it begins to move, because a particle at the extremity of the tube is not to receive its whole circular motion there, but gradually acquires it by a uniform acceleration during its passage along the tube; so that we must here inquire what force will give to the quantity of water $a l w$, in the time $\frac{l}{v}$ of its passing through its respective horizontal arm, the velocity $\frac{2\pi r}{t}$, in the direction of the aperture. Then, according to the rules given for forces in dynamics, we shall have $\frac{12{\cdot}273\, a l v}{t} \times \frac{8{\cdot}0208}{5} = 19{\cdot}6878 \frac{a l v}{t}$ for the resistance in lbs. opposed to each arm, such resistance being estimated as if accumulated at the distance $\frac{1}{2} l$ from the centre of motion.

*Acquired Velocity of the Water.*—According to the theory of hydraulics, the velocity of water issuing through an aperture at the depth $h$ below the upper surface of a reservoir, is expressed by $8{\cdot}0208 \sqrt{h}$, which when reduced, in conformity with the experiments, becomes $5\sqrt{h}$ very nearly; and this is the velocity of the water passing out of the tubes at the commencement of the rotation. Then, as

$$\sqrt{2 a h w} : 5\sqrt{h} :: \sqrt{\left(2 a h w + 76{\cdot}70625 \frac{a l^2}{t^2}\right)} : 5\sqrt{\left(h + 38{\cdot}35312 \frac{l^2}{w t^2}\right)}$$

$$= 5\sqrt{\left(h + {\cdot}61365 \frac{l^2}{t^2}\right)} = v,$$

the required velocity of the water.

*Ratio of the Central Force to the Inertia.*—This will be ascertained by substituting for $v$ in the expression $19{\cdot}6878 \frac{a l v}{t}$, its value just found; so that we have $98{\cdot}439 \frac{a l^2}{t^2} \times \sqrt{\left({\cdot}61365 + \frac{h t^2}{l^2}\right)}$ for the inertia, while the centrifugal force is measured by $76{\cdot}70625 \frac{a l^2}{t^2}$. Now we find that $76{\cdot}70625 \frac{a l^2}{t^2} : 98{\cdot}439 \frac{a l^2}{t^2} \times \sqrt{\left({\cdot}61365 \frac{h t^2}{l^2}\right)} :: 1 : 1{\cdot}2833 \sqrt{\left({\cdot}61365 \frac{h t^2}{l^2}\right)}$, or as $1 : \sqrt{\left(1 + \frac{1{\cdot}646\, h t^2}{l^2}\right)}$ very nearly; which is the ratio of the power gained by the centrifugal force to the obstruction arising from inertia. Whence it appears that the latter is greater than the former, except when $t = 0$, $h = 0$, or $l = \infty$, cases never occurring in practice; and that the longer the arms, the less the fall of water, and the greater the velocity of rotation, the nearer these forces approach to the ratio of equality.

*Adjustment of the Parts and Motion.*—Here it must be particularly observed that the centrifugal force should not exceed the gravity of the water revolving in the arms $g d$, $g e$; for in that case the water would be drawn into the tube faster than it could be naturally supplied at its entrance, by the velocity proper to that depth, and of consequence a vacuum must be occasioned; nor should the velocity of the apertures be greater than half that of the water through them; for the apertures being still adapted in point of magnitude to the velocity, the effluent quantity or number of acting particles is as the time, the momentum is in the simple ratio of the relative velocity, and therefore the greatest effect will be produced when the velocity of the apertures is equal to half that due to the head of water. These two conditions expressed algebraically will furnish the equations,

$$76{\cdot}70625 \frac{a l^2}{t^2} = 2 a l w \ldots . \frac{2\pi l}{t} = \frac{5}{2}\sqrt{h + l};$$

from which equations we deduce the following,

$$\text{namely, } \begin{cases} h = 9{\cdot}29345\, l = 15{\cdot}1446\, t^2, \\ l = 1{\cdot}6296\, t^2 = {\cdot}1076\, h, \\ t = \sqrt{{\cdot}61365}\, l = \sqrt{{\cdot}06603}\, h. \end{cases}$$

Whence it appears that $h$, $l$, and $t^2$, are nearly in the constant ratio of 15, $9\frac{1}{4}$, and 1.

Still it should be observed, that while $l$ and $t$ are preserved in a constant ratio, the values of $76{\cdot}70625 \frac{a l^2}{t^2}$, and of $12{\cdot}273 \frac{a l v}{t}$, that is, of the central force and of the inertia, must remain the same; so that the brachia may be made of any length at pleasure (not less than ${\cdot}1076\, h$) if the time of revolution be taken in a corresponding proportion, or so that the velocity of the apertures undergo no variation, which will be ensured by making $t = \sqrt{{\cdot}61365}\, l$; for a double or triple radius, revolving in a double or triple time, or with half or a third the angular velocity, has the

same absolute velocity at the extremity; and with the same power there applied, will produce the same effect. Hence,

*The moving force and velocity of the machine, when the effect is a maximum*, may be found. For, if we put $\cdot 61365\, l$ for $t^2$, and $9 \cdot 29345\, l$ for $h$, in the expression $\sqrt{\left(1 + \frac{1 \cdot 646\, h\, t^2}{l^2}\right)}$, it becomes $\sqrt{1+3} = 2$; in which case the resistance of inertia is just double the central force, or the gravity of the water in the tube $= 125\, a\, l$, which, taken from the impelling force, leaves $62 \cdot 5\ (a\, h + l) - 125\, a\, l = 62 \cdot 5\, a\ (h - l) = 55 \cdot 775\, a\, h$ lbs. avoirdupois = the real moving force, at the distance of the centres of the apertures from the centre of motion, $l$ being taken $= \cdot 1076\, h$. And by a like substitution, the velocity $\frac{5}{2}\sqrt{h + l}$ becomes $\frac{5}{2}\sqrt{1 \cdot 1076\, h} = 2 \cdot 63205\, \sqrt{h}$, feet per second.

*Area of the Apertures.*—If A = the area of a section of the race perpendicular to the direction of its motion, V = its velocity per second, both in feet, $a$ and $h$ as before; then it will be $\mathrm{AV} = 10\, a\, \sqrt{\left(h + \cdot 61365\, \frac{l^2}{t^2}\right)}$ cubic feet = the quantity of water emitted per second by both apertures: hence $a = \frac{\mathrm{AV}}{14 \cdot 2722\, \sqrt{h}} = \frac{\cdot 070066\, \mathrm{AV}\, \sqrt{h}}{h}$, the area proper for one of the apertures.

From the preceding investigation we may deduce the following rules.

1. Make each arm of the horizontal tube, from the centre of motion to the centre of the aperture, of any convenient length, not less than $\frac{1}{5}$th of the perpendicular height of the water's surface above these centres.

2. Multiply the length of the arm in feet by $\cdot 61365$, and take the square root of the product for the proper time of a revolution in seconds, and adapt the other parts of the machinery to this velocity; or,

3. If the time of a revolution be given, multiply the square of this time by $1 \cdot 6296$ for the proportional length of the arm in feet.

4. Multiply together the breadth, depth, and velocity per second of the race, and divide the last product by $14 \cdot 27$ times the square root of the height, for the area of either aperture; or, multiply the continual product of the breadth, depth, and velocity of the race, by the square root of the height, and by the decimal $\cdot 07$; the last product, divided by the height, will give the area of the aperture.

5. Multiply the area of either aperture by the height of the head of water, and the product by $55 \cdot 775$ (or 56 lbs.), for the moving force, estimated at the centres of the apertures in pounds avoirdupois.

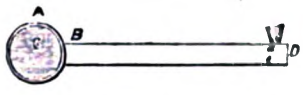
With respect to different forms and developments of reaction water-wheels, we give, with some slight, but necessary, alterations, the following general observations from a treatise on Hydraulics, by J. F. D'Aubuisson de Voisins.

We designate by the appellation *reaction water-wheels* machines in which the water contained in them, and which issues from them with a certain effort, reacts upon the parts of the machine opposite the orifices of issue with an equal effort; in consequence of which it constrains these parts to recoil, and so occasions the motion of rotation. The following example will enable us to appreciate this mode of action; but before giving this example, it is necessary to revert to a principle.

The equality between action and reaction, which is regarded nearly as an axiom in mechanics, has been directly demonstrated by Daniel Bernoulli, in the case of a jet issuing from a vase ('Hydrodynamica,' pp. 279 and 303). He found, by calculation and experiment, that the effort exerted upon the vase by the reaction of the jet was equal to the weight of a prism which had for its base the orifice, and for its height twice the height due to the velocity of issue; and we know that such is the measure of the effort of which the jet is capable.

Let there be a vase or great vertical tube, of which A is the base, Fig. 548, which is movable around its axis C, at the foot of which is fixed a horizontal tube B D, open at B, and closed through its remaining extent. If this apparatus be filled with water, the fluid will exert an equal pressure on all parts of the tube; that which takes place at any point will be destroyed by the pressure upon the point diametrically opposite, and there will be an equilibrium. But if we make an orifice at $a$, for example, there will no longer be a pressure upon this point; that exerted upon the opposite side will be no longer counterbalanced, and it will drive the tube in the direction from $a$ to $e$; the jet issuing at $a$, acting by its *reaction*, will cause the machine to turn around its axis C, and in a direction opposite to its own, in the same manner as the elastic fluid arising from igniting the powder contained in the charge of a squib or rocket, issuing downwards, drives it rapidly upwards.

548.

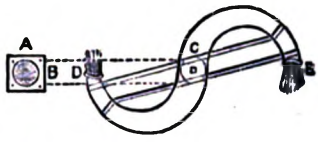



If, at the lower part of the great vertical tube A, we have radiating from it many tubes similar to B D, and similarly pierced, we shall have the machine of reaction designed, towards the middle of the last century, by Segner, professor of mathematics at Göttingen, which the Germans consequently name *Segner's Wheel*.

Euler, having made this an object of his studies ('Académie de Berlin,' 1750), proposed, 1st, to give a curved form to the horizontal tubes, so as to obtain a pressure resulting from the centrifugal force; 2nd, to cause the water to issue through the extremities of the tubes, which extremities he curved so as to make them perpendicular to the radius of the wheel drawn to them.

M. Manouri d'Ectot, profiting by the indication of these improvements, planned a machine such as we see in Fig 549. Its tubes, swelling in the middle, and curved like an $\mathcal{O}$, were united and held by iron bars. The motive water is conveyed to them by means of a great vertical tube, which is bent horizontally at B, and, passing under the wings or revolving arms, rises vertically, and terminates at the common centre C.

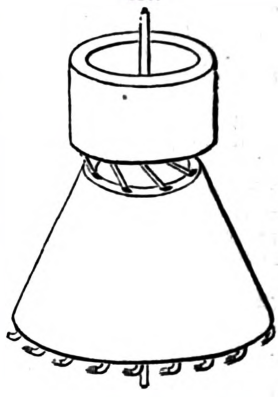
549.




These wheels have been successfully established in the mills of Brittany, of Normandy, and of the environs of Paris; "from authentic experiments, they produced an effect superior to that of the best executed 'pot-wheels,'" says Carnot, in the name of the commission of the Institute appointed to the examination of this machine ('Journal des Mines,' 1813, tom. XXXIII.). However, in common practice, we cannot, without difficulty, keep tight the junction of the stationary part, the tube conducting the water, with the movable part, the wings or arms of the wheel. Otherwise, this wheel seems better fitted than any other to transmit the action of a current of water directed from below upwards, such as issues from certain artesian wells.

Euler, whose ideas upon these reaction machines were derived from Segner's, designed one which seemed to him better fitted to reap the full advantage of this mode of the action of water. It had the form of a great bell, or rather, it was a truncated cone, hollow in the middle, consisting of two concentric surfaces, made of sheet-iron plates, with a space between them, open at the top and closed at the bottom; small bent pipes were fitted vertically all around and at the bottom, their extremities being horizontal and in the direction of the motion, or rather, in a direction opposite to it. The motive water entering at the top of the machine, filled the space between the two conical envelopes, and issued through the small tubes. Though unwieldy, this machine has been used advantageously in France.

550.



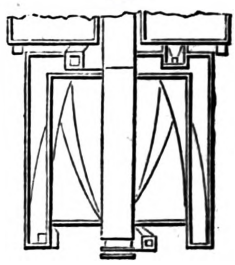
Three years after, Euler gave a more complete theory of reaction wheels; and on this occasion he projected a second, which is described in the 'Mémoires de l'Académie de Berlin,' 1754. It consisted of two parts, placed one above the other as shown in Fig. 550. The upper was immovable, and formed a cylindrical and annular reservoir, with small tubes fixed to the bottom, rectilinear, but inclined at an angle determined by calculation, and delivering the water upon the lower part. The latter, movable around its axis, presented at the top an annular trough, from the bottom of which projected twenty tubes, diverging in their descent, the ends of which, bent horizontally, delivered the water in the air. All of these pipes were covered, as far as the bending, by a smooth sheet-iron surface, designed to lessen the resistance of the air.

Such a machine, with tubes uniformly curved, not being obstructed at their extremity, and not being entirely full of water, has a close resemblance to the duct-wheels of M. Burdin; and the theory of Borda would be equally applicable to it.

The learned engineer whom we have just named, and to whom the works of Euler were unknown, also made a *reaction turbine*, which bears a great resemblance to that of the illustrious geometer. We give a short description of one which he established at the mill of Ardes, in the department of Puy-de-Dôme.

The fall is 6·56 ft. Under a wooden basin, where the water is maintained at a constant height of 3·28 ft., is placed the machine of rotation represented in Fig. 551. Three injecting orifices, fitted to the bottom of the basin, deliver the water horizontally in the crown, or small annular basin, which forms its upper part. It then enters into three pyramidal enclosures, with vertical axes, whose extremities are bent horizontally, having an orifice of issue. The height of the machine is 3·28 ft.; and generally it is one-half the fall.

551.



It is contrived so that the turbine, under the injecting orifices, may have a velocity of 14·53 ft., that due to the height of 3·28 ft. The water arriving upon the machine with a velocity equal to that of the points which receive it, there is no shock. Moreover, the head upon the orifices of the conduits being 3·28 ft., the water will issue from them also with the relative velocity of 14·53 ft.: and as that of the orifices in an opposite direction is the same in value, the absolute velocity of the fluid will be zero. The two conditions necessary for the *maximum* of effect are thus fulfilled, and the dynamic effect of the turbine will be P H. The total fall of the water being put = H. This fall, when it is taken to measure the entire force of the current, is the difference of level between the fluid surfaces of the upper and lower reaches. But for hydraulic wheels it is reckoned from the upper level, or that of the reservoir, to the lowest point of the wheel, as this point may be lowered to the level of the lower reach, when this level is constant. P = the weight of water furnished in one second by the motive current.

But in practice, many circumstances always occur to change the conditions of this greatest effect. Still, M. Burdin has never seen the useful effect of his reaction turbines below 0·65 P H, and sometimes it has been as high as 0·75 P H ('Annales des Mines,' tom. III, 1828).

Nearly a century has elapsed since the theory of reaction machines was the object of Euler's researches: his memoirs upon this subject, which, however, I am not in a situation to properly appreciate, bear, according to competent judges, the impress of his analytical genius. But since their publication, and partly in consequence of the works of this great man, the theory of machines

in motion, especially in all pertaining to their dynamic effect, has reached a much greater degree of generality and simplicity.

For a summary application to reaction wheels of this theory, I will suppose, with M. Navier, that the water enters them without shock, and runs through them without a sudden change of velocity; I shall only then, have to consider its absolute velocity immediately after its exit from the machine. We have remonstrated (see TURBINE WATER-WHEELS) that when water issues through orifices made in the circumference of a wheel in motion around its vertical axis, its velocity, relatively to that of the machine, is, upon the last element of the orifices, $\sqrt{2gh + v^2}$, $h$ being the height of the reservoir above these orifices, and $v$ their velocity of rotation. We suppose their extremity to be horizontal, and perpendicular to the radius of the circumference described; then, their velocity $v$ is found directly opposed to that which the fluid possesses upon this extremity, and its absolute velocity, immediately after quitting it, is then $\sqrt{2gh + v^2} - v$. But the dynamic effect is equal to the force of the motor, minus the half of the *vis viva* which the water possesses after issuing from the machine. and we shall thus have

$$E = Ph - \frac{P}{2g}\left(\sqrt{2gh + v^2} - v\right).$$

This equation shows that the effect is greater, as the complex factor of the second term in the second member is smaller, and that it will be at its *maximum* and equal to $Ph$ when this factor is zero; now, we cannot have $\sqrt{2gh + v^2} - v = 0$, except $v$ is infinite. Whence we conclude that in reaction machines the effect can never be, even in theory, equal to the force of the motor, and that it is greater in proportion as the velocity of rotation is the more considerable.

Finally, in the year 1838, M. Combes, mining engineer, took up the theory of reaction machines, and extended it to all the circumstances of motion; after having studied carefully that of Euler, he established a more general one, which he presented to the Academy of Sciences; but as yet it has not been published. From the short notice upon this subject, inserted in the reports of the sessions of the Academy of Sciences (session of 6th August), the formulæ of M. Combes indicate in reaction machines what those of M. Poncelet have shown for turbines, that the velocity of the wheel may experience great variations, either increasing or decreasing, from that giving the *maximum* of effect, without a marked diminution in this effect. "It is necessary," observes the author, "that the gates of the reaction wheel should be fixed upon the wheel itself; and in order that the useful effect may remain always the same, notwithstanding the variations in the volume of water, it is requisite that the gates should act at once upon the whole of the orifices of entry and issue of the movable pipes, which should have between them a constant ratio, determined by the equation of motion."

See FLOAT WATER-WHEELS. OVERSHOT WATER-WHEELS. TURBINE WATER-WHEELS. UNDERSHOT WATER-WHEELS.

BAROMETER. FR., *Baromètre;* GER., *Barometer;* ITAL., *Barometro;* SPAN., *Barómetro.*

A barometer is an instrument for determining the weight or pressure of the atmosphere, and hence the actual and probable changes of the weather, or the height of any ascent.

The form commonly used was invented by Torricelli at Florence in 1643. It consists of a glass tube, 33 or 34 in. in length, closed at top, filled with mercury, except the vacuum at the top, and inverted in an open cup of mercury. A graduated scale is attached to the tube to note the variations of the column of mercury.

The *Aneroid barometer* is a form of the instrument in which the atmosphere acts upon the elastic top of a thin metallic box, which has previously been partially exhausted of air, and furnished with levers and an index to note the changes produced by atmospheric pressure.

The *Siphon barometer* is another form of the common barometer.

The *Sympiesometer* is another form of barometer.

A *Marine barometer* is a barometer with tube contracted at the bottom to prevent rapid oscillations of the mercury; it is suspended in gimbals from an arm or support on shipboard.

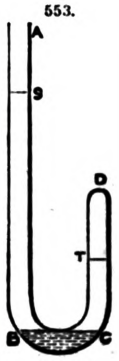
A *Mountain barometer* is a portable mercurial barometer, with tripod support, and a cong, for measuring heights.

A *Wheel barometer* is a barometer with recurved tube and a float, from which a cord by passing over a pulley moves an index.

Experiments show that if a vessel be exhausted of air it will be lighter than when it was full, hence air has weight. And we show (see HYDROSTATIC BALANCE) how the weight and *specific gravity* of air may be accurately determined. The weight of a column of the atmosphere is shown by the barometer; for, let A B, Fig. 552, be a glass tube, 34 in. long, open at A and closed at B. Fill the tube with mercury, and placing the finger firmly on the end A, so as to prevent the mercury from escaping out of the tube, invert it, and plunge the end A into a vessel C D, of mercury. If the finger be now removed, it will be found that the mercury will stand at about 29 or 30 in. in the tube above the level of the mercury in the basin. That the mercury is sustained in the tube by the pressure of the air upon the surface of the mercury in the basin may be proved by placing the barometer under the receiver of an air-pump. As the air is exhausted, the mercury sinks in the tube; and when the exhaustion is so complete that very little pressure is exerted on the surface of the mercury in the basin, the mercury in the tube and in the basin are nearly on the same level. On the air being again admitted into the receiver, the mercury rises in the tube to its former height. Since the pressure of a fluid on any portion of the surface is the weight of the superincumbent column of the fluid,

the pressure of the mercury upwards against the surface C D, is the weight of a column of mercury, whose base is C D and altitude P E; and this pressure is balanced by the pressure of the air downwards on the surface C D. From numerous experiments it has been found that the density of air is proportional to the force that compresses it. For let A B C D, Fig. 553, be a bent cylindrical tube of glass, having one end A open and the other D closed. Suppose the communication between the two branches to be cut off by a small quantity of mercury poured in at A until it just fills the base B C. Then the air in C D will be of the same density as the air in A B. If more mercury be poured in at A, it will force the mercury to rise in D C; and if this pouring be continued until the mercury stands at S, as high above the point T, to which it has risen in D C, as the altitude of the mercury in the barometer, then that column of mercury, from what we have before shown, is equivalent to the weight of the column of air incumbent upon it. Hence the pressure against the air in D T, arising from the pressure of the atmosphere and the mercury in S B, is twice as great as it was against the air in C D; and it has been observed that D T = ½ C D; therefore, the air being compressed into half the space, the density is doubled. In like manner, if another column of mercury be added, so that the altitude of the mercury in A B, above the mercury in C D, shall be twice the altitude of the mercury in the barometer, the pressure of the air in D T, arising from the weight of the atmosphere and the mercury in S B, will now be three times as great as it was against the air in C D. Also D T has been found to be = ⅓ C D, and, therefore, the density in D T is = 3 times the density of the atmosphere. In this way the density has been found in all cases, within a moderate extent, to be proportional to the compressing force. And since the force that compresses the air is balanced by the elasticity of the air, it is evident that the elastic force of the air is equal to the compressing force, and may be measured by it. Also it follows, that the elasticity of the air is proportional to its density. This is the law of Boyle.

553.




Gay-Lussac found by experiment, that all gases, under the same pressure, expand uniformly for equal increments of temperature; this is true, at least, from the freezing to the boiling point of the thermometer. Suppose a column of the atmosphere to rest on a base whose area is 1; and suppose this column to be divided into an infinite number of strata, of equal thickness, parallel to the horizon. Then, since each stratum of air is compressed by the weight of those above it, the lower strata will be more compressed, and, therefore, will be denser than those above them.

The nature and properties of both atmospheric air and mercury have been carefully ascertained; so far, the determination of the heights of mountains by the barometer presents no difficulty; but, to solve the ultimate equation, has, up to the present time, defied the skill of mathematicians. The formulas presented by writers on mechanics to effect this object, only gave approximate results. This ultimate equation, which may be presented under the form [1], can be solved with the greatest ease by dual arithmetic, a new art.

$$z = \frac{k(1+\alpha\tau)}{g}\left(1+\frac{z}{r}\right)\log._{\epsilon}\left[\frac{H}{h}\left(1+\frac{z}{r}\right)^{2}\right]. \qquad [1]$$

In this equation all the quantities, except the required height $z$, are known; the logs. are hyperbolic, and this equation may be put under the form

$$\sqrt{\frac{H}{h}\left(1+\frac{z}{r}\right)} = \sqrt{\frac{H}{h}} + \frac{k(1+\alpha\tau)}{rg}\sqrt{\frac{H}{h}\left(1+\frac{z}{r}\right)}\log._{\epsilon}\left[\frac{H}{h}\left(1+\frac{z}{r}\right)\right];$$

in this last equation put $\sqrt{\frac{H}{h}} = A$; and suppose A = hyperbolic log. of $a$, that is, suppose $\log._{\epsilon} a = A$; put $x = \sqrt{\frac{H}{h}\left(1+\frac{z}{r}\right)}$, and $B = \frac{k(1+\alpha\tau)}{rg}$.

These substitutions being made, [1] becomes

$$x = A + Bx\log._{\epsilon} x^{2}. \qquad [2]$$

The base of the hyperbolic system of logarithms $\epsilon = 2{\cdot}718281828$ and the dual logarithm of $\epsilon = 100000000, = 10^{8}$, the dual logarithm of $\epsilon$ is written $\downarrow, \epsilon = 10^{8}$. Equation [2] may be put under the form $\epsilon^{x} = a\,x^{2Bx}$; taking the $x$th root of both sides of the last equation, we have $\epsilon = a^{\frac{1}{x}}\,x^{2B}$.

Put $n^{2B} = \epsilon$, then $\frac{n^{2B}}{x^{2B}} = a^{\frac{1}{x}}$; therefore, $\left(\frac{n}{x}\right)^{x} = a^{\frac{1}{2B}}$; or $\left(\frac{x}{n}\right)^{x} = \frac{1}{a^{\frac{1}{2B}}}$; consequently $\left(\frac{x}{n}\right)^{\frac{x}{n}} = \left(\frac{1}{a^{\frac{1}{2B}}}\right)^{\frac{1}{n}}$. If $c$ be put for the known quantity $\left(\frac{1}{a^{\frac{1}{2B}}}\right)^{\frac{1}{n}}$ and $y$ for $\frac{x}{n}$, the last equation becomes $y^{y} = c$, hence in a dual form we have $y\downarrow, (y) = \downarrow, (c)$; [3]. A general solution of all equations of the form [3], is given in Part II. of the 'Art and Science of Dual Arithmetic,' by Oliver Byrne.

In measuring heights by the barometer, it is necessary to know, to the greatest nicety, the ratio of the density of mercury to that of air. The accurate and indefatigable M. Regnault found, at Paris, that a litre of air at 0° centigrade, under a pressure of 760 millimètres, weighed 1·293187 grammes; and at the level of the sea, in latitude 45°, it weighed 1·292697 grammes. He also found that a litre of mercury, at the temperature of 0° cent., weighed 13595·93 grammes.

A litre of water, at its maximum density, weighs 1000 grammes; therefore the ratio of the density of mercury to that of air, in latitude 45°, will be $= \frac{13595 \cdot 93}{1 \cdot 292697} = 10517 \cdot 49$.

At Paris, a litre of atmospheric air weighs 1·293187 grammes; but this number is only correct for the locality in which the experiments were made—that is, the latitude of 48° 50′ 14″, and a height of 60 mètres above the level of the sea. Taking 1·292697 grammes for the weight of a litre of air under the parallel of 45° latitude, and at the same distance from the centre of the earth as that at which the experiments were tried, to be 1·292697 grammes, then, putting $w$ for the weight of the litre of air, in any other latitude, any other distance from the centre of the earth,

$$w = \frac{1 \cdot 292697\,(1 \cdot 00001885)\,(1 - \cdot 002837)\cos.\,\lambda}{1 + \frac{2q}{n}}. \qquad [4]$$

$n = 6366198$ mètres, the mean radius of the earth, $q$ the height of the place of observation above the mean radius, and $\lambda$ the latitude of the place. In applying formula [4] to a particular example, the author found that at Philadelphia, U.S., lat. 39° 56′ 51″·5 N., the weight of a litre of air was 1·2914392 grammes; the ratio of the density of mercury to that of air at the level of the sea was 10527·735; and $n = 6367653$ mètres at Philadelphia.

Regnault also found, by experiments, that 1·36706 represents the volume of air at 100° centigrade thermom., the volume at 0° being supposed = 1. Before the time of Regnault, these and many other constants were greatly in error. Experiments show that air, under the same pressure, expands uniformly for equal increments of temperature; that the expansion due to the same increase of temperature is not the same for all gases, as many scientific men have supposed. However, in air the expansion for a unit of bulk is ·36706, according to Regnault, from the freezing to the boiling points; and therefore the expansion for each degree of Fahrenheit is $\frac{1}{180}$ of ·36706.

Let $\alpha$ = the expansion of air for each degree of the thermometer, $k$ = the ratio of the elasticity of air to its density at the temperature of melting ice; then the bulk at the temperature $x$ will be increased, and therefore the density diminished in the ratio of $1 + \alpha x$ to 1; consequently $k(1 + \alpha x)$ = the ratio of the elasticity to the density at the temperature $x$.

For the air, let
$p$ = the elasticity, $g$ = the force of gravity, } at the surface of the earth;
P = the elasticity, D = the density at temp. $x$, G = the force of gravity, } at the altitude $z$ above the surface;

then $\frac{\mathrm{P}}{\mathrm{D}} = k(1 + \alpha x)$, and $\therefore \mathrm{P} = \mathrm{D}\,k(1 + \alpha x)$.

Then, for what is conventionally termed the differential of P, in the notation of the differential calculus, put $d\mathrm{P}$;

therefore, $\mathrm{P} - d\mathrm{P}$ = the pressure at the altitude $(z + dz)$,
P = the pressure at the altitude $z$.

$\therefore -d\mathrm{P}$ = the difference of pressures $= \mathrm{D\,G}\,dz = \frac{\mathrm{D}\,g\,r^2\,dz}{(r+z)^2}$; $r$ being put for the radius of the earth where the observation is made.

$$\therefore -\frac{d\mathrm{P}}{\mathrm{P}} = \frac{g\,r^2}{k(1+\alpha x)}\left(\frac{1}{(r+z)^2}\right), \text{ and hence, by integrating, we find}$$

$$\log_e \mathrm{P} = \frac{g\,r^2}{k(1+\alpha x)}\left(\frac{1}{(r+z)}\right) + \text{constant},$$

$$\therefore \log_e p = \frac{g\,r^2}{k(1+\alpha x)}\left(\frac{1}{r}\right) + \text{constant};$$

$$\text{consequently, } \log_e p - \log_e \mathrm{P} = \log_e \frac{p}{\mathrm{P}} = \frac{g\,r^2}{k(1+\alpha x)}\left(\frac{1}{r} - \frac{1}{r+z}\right);$$

$$\therefore \log_e \frac{p}{\mathrm{P}} = \frac{g\,z}{k(1+\alpha x)}\left(\frac{r}{r+z}\right). \qquad [5]$$

From experiment it also appears that mercury contracts uniformly as its temperature decreases.

For mercury, let
H = height of barometer, M = density of mercury, T = temperature of mercury, } at the surface of the earth;

and $\mathrm{H}_1$, $\mathrm{M}_1$, $\mathrm{T}_1$, the same quantities respectively at the altitude $z$; and $\frac{1}{\beta}$ = the condensation of mercury for one degree of the thermometer; therefore, $\mathrm{M}_1 = \mathrm{M}\left(1 + \frac{\mathrm{T} - \mathrm{T}_1}{\beta}\right)$; but, $p = g\,\mathrm{H\,M}$: and $\mathrm{P} = \mathrm{G\,H_1\,M_1} = \frac{g\,r^2}{(r+z)^2}(\mathrm{H_1})\,\mathrm{M}\left(1 + \frac{\mathrm{T} - \mathrm{T}_1}{\beta}\right)$;

$$\therefore \frac{p}{\mathrm{P}} = \left(\frac{r+z}{r}\right)^2 \frac{\mathrm{H}}{\left(1 + \frac{\mathrm{T} - \mathrm{T}_1}{\beta}\right)\mathrm{H}_1}.$$

Putting $h$ for $\left(1 + \frac{\mathrm{T} - \mathrm{T}_1}{\beta}\right)\mathrm{H}_1$, and equating the hyperbolic logarithms of the last value of

$\frac{p}{P}$ with the value before found [5], we have $\frac{g z}{k(1+\alpha x)}\left(\frac{r}{r+z}\right) = \log_{\epsilon}\left\{\frac{H}{h}\left(1+\frac{z}{r}\right)^2\right\}$;

$$\therefore z = \frac{k(1+\alpha x)}{g}\left(1+\frac{z}{r}\right)\log_{\epsilon}\left[\frac{H}{h}\left(1+\frac{z}{r}\right)^2\right].$$

The temperature $x$ has been supposed to remain the same throughout the whole column $z$, whereas it always decreases as we ascend from the surface of the earth; but, being ignorant of the law of this change, a mean value ($\tau$) between the values at the two stations is taken and considered constant: the mean $\tau$, being substituted for $x$ in the last equation, [1] is established.

We append the barometrical Tables of M. Mathrew, from which the heights of mountains may be found by mere inspection. This method will be found useful when great accuracy is not required, or when an observer wishes to avoid the labour of calculating.

These Tables, based upon Laplace's formula, are sufficiently extended to enable heights—or rather, differences of level—to be calculated to nearly 9000 mètres.

Let us suppose the following observations to have been made:—

At the lower station { H, height of the barometer; T, temperature of the barometer; $t$, temperature of the air.

At the upper station { $h$, height of the barometer; T', temperature of the barometer; $t'$, temperature of the air.

The height $h$ of the barometer, at the temperature T', observed at the upper station, becomes $h'$ when brought to the temperature T of the barometer at the lower station. Now, for every degree centigrade, the expansion of mercury is 0·00018002; that of brass, according to the barometric scale, is 0·00001878; and the difference of these two expansions is $0{\cdot}00016124 = \frac{1}{6200}$; therefore we have $h' = h\left(1+\frac{T-T'}{6200}\right)$.

Let $s$ be the height of the lower station above the level of the sea, and L the latitude of the place. The difference of level Z between the two stations is

$$Z = 18336^{m}\log.\frac{H}{h'} \times \left\{\begin{array}{l}\left\{1+\frac{2(t+t')}{1000}\right\}\\ (1+0{\cdot}00265\cos.2L)\\ \left(1+\frac{Z+15926}{6366198}+\frac{s}{3183099}\right)\end{array}\right\}$$

This is the formula to which the equation of *Celestial Mechanics* is brought by introducing the term $\frac{s}{3183099}$, which is relative to the height $s$ of the lower station above the sea.

But we have just found $h' = h\left(1+\frac{T-T'}{6200}\right)$; therefore, by calling M = 0·4342945 the modulus of the logarithms, we shall have $\log. h' = \log. h + M\frac{T-T'}{6200}$,

then $18336^{m}\log. h' = 18336^{m}\log. h + 1^{m}{\cdot}2843\,(T-T')$,

and lastly, $18336^{m}\log.\frac{H}{h'} = 18336^{m}\log.\frac{H}{h} - 1^{m}{\cdot}2843\,(T-T')$,

and we shall be enabled, after the substitution, to put the foregoing equation in the following form:—

$$Z = \left(18336^{m}\log.\frac{H}{h} - 1^{m}{\cdot}2843\,(T-T')\right) \times \left\{\begin{array}{l}\left\{1+\frac{2(t+t')}{1000}\right\}\\ \left(1+0{\cdot}00265\cos.2L+\frac{Z+15926}{6366198}\right)\\ \left(1+\frac{s}{3183099}\right)\end{array}\right\}$$

It is from this complete formula, with all the data of the observations H, $h$, T, T', $t$ and $t'$, that the following barometrical Tables have been constructed.

After having calculated the first approximate value of Z,

$$a = 18336^{m}\log.\frac{H}{h} - 1^{m}{\cdot}2483\,(T-T'),$$

and the second, $A = a\frac{2(t+t')}{1000}$, we shall have

$$Z = A\left\{\begin{array}{l}\left(1+0{\cdot}00265\cos.2L+\frac{A+15926}{6366198}\right)\\ \left(1+\frac{s}{3183099}\right)\end{array}\right\}$$

Table I. gives the metrical values of $18336^{m}\log. H$ and of $18336^{m}\log. h$ for barometrical heights from 265 to 801 millimètres; only, all those values are diminished by the constant $44428^{m}{\cdot}128$, which neither alters the value of the term $18336^{m}\log.\frac{H}{h}$ nor of the difference $18336^{m}\log. H - 18336^{m}\log. h$.

Table II. gives the correction $-1^{m}\cdot2843\,(T-T')$ dependent upon the difference $T-T'$ in the temperatures of the barometer at the two stations. It is generally subtractive. It would be additive if $T-T'$ were negative, that is, if the temperature T' of the barometer, at the upper station, were greater than the temperature T at the lower station.

If the barometrical scale were divided upon glass or upon a wooden mounting, the correction, which then would become $-1^{m}\cdot43\,(T-T')$, would be directly obtainable by calculation.

Table III. gives, for an approximate height A, and the latitude L, the correction, always additive,

$$A\left\{0\cdot00265\cos.\,2L+\frac{A+15926}{6366198}\right\}.$$

The first term $A\,0\cdot00265\cos.\,2L$ arises from the variation of gravity between the latitude of 45 degrees and the latitude L of the place of observation. It is positive between the equator and 45 degrees, and negative between 45 degrees and the pole.

The second term $\frac{A+15926}{6366198}A$ is due to the diminution of gravity in the vertical between the two stations; it is always positive and larger than the first. The sum of these two terms has, therefore, the advantage of being always positive.

The small correction $A\frac{s}{3183099}$ is owing to the height $s$ of the lower station above the sea. That height is known, but, with an approximation amply sufficient, we may take

$$s=18336^{m}\log.\frac{760}{H}.$$

The correction then becomes $A\,0\cdot00576\log.\frac{760}{H}$

It is always additive, and is given in Table IV. It is obtained at the lower station, together with A and the height H of the barometer.

*Method of performing the Calculation.*—Take from Table I. the two numbers corresponding to the barometrical heights H and $h$, obtained by observation. From this difference subtract the correction $1^{m}\cdot2843\,(T-T')$, which will be found in Table II., together with the thermometrical difference $T-T'$ of the barometers. The approximate height $a$ will thus be got.

The correction $a\frac{2\,(t+t')}{1000}$, for the temperature of the air, has next to be calculated by multiplying the thousandth part of $a$ by twice the sum of the temperatures $t$ and $t'$. It bears the same sign as $t+t'$. A second approximate height A is then obtained.

Having A and the latitude L of the place, find, in Table III., the correction, always additive, $A\left\{0\cdot00265\cos.\,2L+\frac{A+15926}{6366198}\right\}$, which arises from the variation of gravity in latitude, and its diminution in the vertical between the two stations.

When the height of the lower station is rather great, or when the height H of the barometer at that station is below 750 millimètres, Table IV. will give the additive correction

$$A\,0\cdot00576\log.\frac{760}{H}.$$

This Table has a double entry, but the correction, which never varies very much, may be easily gathered at sight when it is wished to take it into account.

*Example.*—Measurement of the height of Mont Blanc, by MM. Bravais and Martins, on the 29th August, 1844. Mean latitude, 46 degrees.

| | |
|---|---|
| At the lower station: | |
| Height of the barometer at the Observatory of Geneva .. .. | $H=729^{mm}\cdot65$ |
| Barometrical thermometer .. .. .. .. .. .. .. .. .. | $T=18^{\circ}\cdot6$ |
| Free thermometer .. .. .. .. .. .. .. .. .. .. | $t=19^{\circ}\cdot3$ |
| At the upper station, 1 mètre below the summit: | |
| Height of the barometer .. .. .. .. .. .. .. .. .. | $h=424^{mm}\cdot05$ |
| Barometrical thermometer .. .. .. .. .. .. .. .. .. | $T'=-4^{\circ}\cdot2$ |
| Free thermometer .. .. .. .. .. .. .. .. .. .. | $t'=-7^{\circ}\cdot6$ |
| Table I. gives for $H=729^{mm}\cdot65$ .. .. .. .. .. .. .. | $8069^{m}\cdot9$ |
| Table I. gives for $h=424^{mm}\cdot05$ .. .. .. .. .. .. .. | $-3748^{m}\cdot1$ |
| Difference .. .. .. .. | $4321^{m}\cdot8$ |
| Table II. gives for $T-T'=22^{\circ}\cdot8$ .. .. .. .. .. .. .. | $-29^{m}\cdot3$ |
| First approximate height $a$ .. .. .. .. .. .. .. .. .. | $4292^{m}\cdot5$ |
| Correction $\frac{a}{1000}2\,(t+t')=4\cdot292\times23\cdot4$ .. .. .. .. .. .. | $+100^{m}\cdot4$ |
| Second approximate height A .. .. .. .. .. .. .. .. | $4392^{m}\cdot9$ |
| Table III. gives for $A=4392\cdot9$ and $L=46^{\circ}$ .. .. .. .. .. | $+13^{m}\cdot4$ |
| Table IV. gives for $H=729^{mm}$ and $4400^{m}$ .. .. .. .. .. .. | $+0^{m}\cdot4$ |
| Difference of level between the two stations .. .. | $4406^{m}\cdot9$ |

By adding 408 mètres to this difference of level—the height of the Observatory of Geneva above the sea, and 1 mètre more for the distance of the upper station below the summit we find the height of Mont Blanc to be $4815^{m}\cdot9$ above the level of the sea.

## Table I.

Value of 1833$^{m}$ log. H, and the value of 18336$^{m}$ log. $h$, in mètres, diminished by the constant 44428$^{m}$·128.
H, $h$, millimètres, height of mercury in the barometer tube, at the lower and upper stations, respectively.

| H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 265 | 4·5 | 30·0 | 330 | 1751·3 | 24·1 | 395 | 3183·1 | 20·1 | 460 | 4396·2 | 17·3 |
| 266 | 34·5 | 29·9 | 331 | 1775·4 | 24·0 | 396 | 3203·2 | 20·1 | 461 | 4413·5 | 17·3 |
| 267 | 64·4 | 29·7 | 332 | 1799·4 | 24·0 | 397 | 3223·3 | 20·0 | 462 | 4430·8 | 17·2 |
| 268 | 94·1 | 29·7 | 333 | 1823·4 | 23·9 | 398 | 3243·3 | 20·0 | 463 | 4448·0 | 17·1 |
| 269 | 123·8 | 29·6 | 334 | 1847·3 | 23·8 | 399 | 3263·3 | 19·9 | 464 | 4465·1 | 17·2 |
| 270 | 153·4 | 29·4 | 335 | 1871·1 | 23·7 | 400 | 3283·2 | 19·9 | 465 | 4482·3 | 17·1 |
| 271 | 182·8 | 29·3 | 336 | 1694·8 | 23·7 | 401 | 3303·1 | 19·8 | 466 | 4499·4 | 17·1 |
| 272 | 212·1 | 29·2 | 337 | 1918·5 | 23·6 | 402 | 3322·9 | 19·8 | 467 | 4516·5 | 17·0 |
| 273 | 241·3 | 29·2 | 338 | 1942·1 | 23·5 | 403 | 3342·7 | 19·8 | 468 | 4533·5 | 17·0 |
| 274 | 270·5 | 29·0 | 339 | 1965·6 | 23·5 | 404 | 3362·5 | 19·7 | 469 | 4550·5 | 17·0 |
| 275 | 299·5 | 28·9 | 340 | 1989·1 | 23·4 | 405 | 3382·2 | 19·6 | 470 | 4567·5 | 16·9 |
| 276 | 328·4 | 28·8 | 341 | 2012·5 | 23·3 | 406 | 3401·8 | 19·6 | 471 | 4584·4 | 16·9 |
| 277 | 357·2 | 28·7 | 342 | 2035·8 | 23·2 | 407 | 3421·4 | 19·5 | 472 | 4601·3 | 16·8 |
| 278 | 385·9 | 28·6 | 343 | 2059·0 | 23·2 | 408 | 3440·9 | 19·5 | 473 | 4618·1 | 16·8 |
| 279 | 414·5 | 28·5 | 344 | 2082·2 | 23·1 | 409 | 3460·4 | 19·5 | 474 | 4634·9 | 16·8 |
| 280 | 443·0 | 28·3 | 345 | 2105·3 | 23·1 | 410 | 3479·9 | 19·4 | 475 | 4651·7 | 16·8 |
| 281 | 471·3 | 28·3 | 346 | 2128·4 | 23·0 | 411 | 3499·3 | 19·3 | 476 | 4668·5 | 16·7 |
| 282 | 499·6 | 28·2 | 347 | 2151·4 | 22·9 | 412 | 3518·6 | 19·3 | 477 | 4685·2 | 16·7 |
| 283 | 527·8 | 28·1 | 348 | 2174·3 | 22·8 | 413 | 3537·9 | 19·3 | 478 | 4701·9 | 16·6 |
| 284 | 555·9 | 28·0 | 349 | 2197·1 | 22·8 | 414 | 3557·2 | 19·2 | 479 | 4718·5 | 16·6 |
| 285 | 583·9 | 27·9 | 350 | 2219·9 | 22·7 | 415 | 3576·4 | 19·2 | 480 | 4735·1 | 16·6 |
| 286 | 611·8 | 27·8 | 351 | 2242·6 | 22·7 | 416 | 3595·6 | 19·1 | 481 | 4751·7 | 16·5 |
| 287 | 639·6 | 27·7 | 352 | 2265·3 | 22·6 | 417 | 3614·7 | 19·1 | 482 | 4768·2 | 16·5 |
| 288 | 667·3 | 27·6 | 353 | 2287·9 | 22·5 | 418 | 3633·8 | 19·0 | 483 | 4784·7 | 16·5 |
| 289 | 694·9 | 27·5 | 354 | 2310·4 | 22·5 | 419 | 3652·8 | 19·0 | 484 | 4801·2 | 16·4 |
| 290 | 722·4 | 27·4 | 355 | 2332·9 | 22·4 | 420 | 3671·8 | 18·9 | 485 | 4817·6 | 16·4 |
| 291 | 749·8 | 27·3 | 356 | 2355·3 | 22·3 | 421 | 3690·7 | 18·9 | 486 | 4834·0 | 16·4 |
| 292 | 777·1 | 27·2 | 357 | 2377·6 | 22·3 | 422 | 3709·6 | 18·8 | 487 | 4850·4 | 16·3 |
| 293 | 804·3 | 27·2 | 358 | 2399·9 | 22·2 | 423 | 3728·4 | 18·8 | 488 | 4866·7 | 16·3 |
| 294 | 831·5 | 27·0 | 359 | 2422·1 | 22·1 | 424 | 3747·2 | 18·8 | 489 | 4883·0 | 16·3 |
| 295 | 858·5 | 27·0 | 360 | 2444·2 | 22·1 | 425 | 3766·0 | 18·7 | 490 | 4899·3 | 16·2 |
| 296 | 885·5 | 26·8 | 361 | 2466·3 | 22·0 | 426 | 3784·7 | 18·7 | 491 | 4915·5 | 16·2 |
| 297 | 912·3 | 26·8 | 362 | 2488·3 | 22·0 | 427 | 3803·4 | 18·6 | 492 | 4931·7 | 16·2 |
| 298 | 939·1 | 26·7 | 363 | 2510·3 | 21·9 | 428 | 3822·0 | 18·6 | 493 | 4947·9 | 16·1 |
| 299 | 965·8 | 26·6 | 364 | 2532·2 | 21·9 | 429 | 3840·6 | 18·5 | 494 | 4964·0 | 16·1 |
| 300 | 992·4 | 26·5 | 365 | 2554·1 | 21·8 | 430 | 3859·1 | 18·5 | 495 | 4980·1 | 16·1 |
| 301 | 1018·9 | 26·4 | 366 | 2575·9 | 21·7 | 431 | 3877·6 | 18·5 | 496 | 4996·2 | 16·0 |
| 302 | 1045·3 | 26·3 | 367 | 2597·6 | 21·7 | 432 | 3896·1 | 18·4 | 497 | 5012·2 | 16·0 |
| 303 | 1071·6 | 26·2 | 368 | 2619·3 | 21·6 | 433 | 3914·5 | 18·4 | 498 | 5028·2 | 16·0 |
| 304 | 1097·8 | 26·2 | 369 | 2640·9 | 21·5 | 434 | 3932·9 | 18·3 | 499 | 5044·2 | 16·0 |
| 305 | 1124·0 | 26·1 | 370 | 2662·4 | 21·5 | 435 | 3951·2 | 18·3 | 500 | 5060·2 | 15·9 |
| 306 | 1150·1 | 26·0 | 371 | 2683·9 | 21·5 | 436 | 3969·5 | 18·2 | 501 | 5076·1 | 15·9 |
| 307 | 1176·1 | 25·9 | 372 | 2705·4 | 21·3 | 437 | 3987·7 | 18·2 | 502 | 5092·0 | 15·8 |
| 308 | 1202·0 | 25·8 | 373 | 2726·7 | 21·3 | 438 | 4005·9 | 18·2 | 503 | 5107·8 | 15·8 |
| 309 | 1227·8 | 25·7 | 374 | 2748·0 | 21·3 | 439 | 4024·1 | 18·1 | 504 | 5123·6 | 15·8 |
| 310 | 1253·5 | 25·6 | 375 | 2769·3 | 21·2 | 440 | 4042·2 | 18·1 | 505 | 5139·4 | 15·8 |
| 311 | 1279·1 | 25·6 | 376 | 2790·5 | 21·2 | 441 | 4060·3 | 18·0 | 506 | 5155·2 | 15·7 |
| 312 | 1304·7 | 25·5 | 377 | 2811·7 | 21·1 | 442 | 4078·3 | 18·0 | 507 | 5170·9 | 15·7 |
| 313 | 1330·2 | 25·4 | 378 | 2832·8 | 21·0 | 443 | 4096·3 | 18·0 | 508 | 5186·6 | 15·7 |
| 314 | 1355·6 | 25·3 | 379 | 2853·8 | 21·0 | 444 | 4114·3 | 17·9 | 509 | 5202·3 | 15·6 |
| 315 | 1380·9 | 25·2 | 380 | 2874·8 | 20·9 | 445 | 4132·2 | 17·9 | 510 | 5217·9 | 15·6 |
| 316 | 1406·1 | 25·2 | 381 | 2895·7 | 20·9 | 446 | 4150·1 | 17·8 | 511 | 5233·5 | 15·6 |
| 317 | 1431·3 | 25·1 | 382 | 2916·6 | 20·8 | 447 | 4167·9 | 17·8 | 512 | 5249·1 | 15·5 |
| 318 | 1456·4 | 25·0 | 383 | 2937·4 | 20·8 | 448 | 4185·7 | 17·8 | 513 | 5264·6 | 15·5 |
| 319 | 1481·4 | 24·9 | 384 | 2958·2 | 20·7 | 449 | 4203·5 | 17·7 | 514 | 5280·1 | 15·5 |
| 320 | 1506·3 | 24·8 | 385 | 2978·9 | 20·7 | 450 | 4221·2 | 17·7 | 515 | 5295·6 | 15·4 |
| 321 | 1531·1 | 24·8 | 386 | 2999·6 | 20·6 | 451 | 4238·9 | 17·6 | 516 | 5311·0 | 15·4 |
| 322 | 1555·9 | 24·7 | 387 | 3020·2 | 20·5 | 452 | 4256·5 | 17·6 | 517 | 5326·4 | 15·4 |
| 323 | 1580·6 | 24·6 | 388 | 3040·7 | 20·5 | 453 | 4274·1 | 17·6 | 518 | 5341·8 | 15·4 |
| 324 | 1605·2 | 24·6 | 389 | 3061·2 | 20·4 | 454 | 4291·7 | 17·5 | 519 | 5357·2 | 15·3 |
| 325 | 1629·8 | 24·4 | 390 | 3081·6 | 20·4 | 455 | 4309·2 | 17·5 | 520 | 5372·5 | 15·3 |
| 326 | 1654·2 | 24·4 | 391 | 3102·0 | 20·4 | 456 | 4326·7 | 17·4 | 521 | 5387·8 | 15·3 |
| 327 | 1678·6 | 24·3 | 392 | 3122·4 | 20·3 | 457 | 4344·1 | 17·4 | 522 | 5403·1 | 15·2 |
| 328 | 1702·9 | 24·3 | 393 | 3142·7 | 20·2 | 458 | 4361·5 | 17·4 | 523 | 5418·3 | 15·2 |
| 329 | 1727·2 | 24·1 | 394 | 3162·9 | 20·2 | 459 | 4378·9 | 17·3 | 524 | 5433·5 | 15·2 |
| 330 | 1751·3 | | 395 | 3183·1 | | 460 | 4396·2 | | 525 | 5448·7 | |

TABLE I.—*continued.*

| H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. | H or h. | Mètres. | Difference. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 525 | 5448·7 | 15·2 | 594 | 6432·0 | 13·4 | 663 | 7307·1 | 12·0 | 732 | 8095·5 | 10·9 |
| 526 | 5463·9 | 15·1 | 595 | 6445·4 | 13·4 | 664 | 7319·1 | 12·0 | 733 | 8106·4 | 10·9 |
| 527 | 5479·0 | 15·1 | 596 | 6458·8 | 13·4 | 665 | 7331·1 | 12·0 | 734 | 8117·3 | 10·8 |
| 528 | 5494·1 | 15·1 | 597 | 6472·2 | 13·3 | 666 | 7343·1 | 12·0 | 735 | 8128·1 | 10·8 |
| 529 | 5509·2 | 15·0 | 598 | 6485·5 | 13·3 | 667 | 7355·1 | 11·9 | 736 | 8138·9 | 10·8 |
| 530 | 5524·2 | 15·0 | 599 | 6498·8 | 13·2 | 668 | 7367·0 | 11·9 | 737 | 8149·7 | 10·8 |
| 531 | 5539·2 | 15·0 | 600 | 6512·0 | 13·3 | 669 | 7378·9 | 11·9 | 738 | 8160·5 | 10·8 |
| 532 | 5554·2 | 14·9 | 601 | 6525·3 | 13·3 | 670 | 7390·8 | 11·8 | 739 | 8171·3 | 10·8 |
| 533 | 5569·1 | 15·0 | 602 | 6538·6 | 13·2 | 671 | 7402·6 | 11·9 | 740 | 8182·1 | 10·8 |
| 534 | 5584·1 | 14·9 | 603 | 6551·8 | 13·2 | 672 | 7414·5 | 11·9 | 741 | 8192·9 | 10·7 |
| 535 | 5599·0 | 14·8 | 604 | 6565·0 | 13·2 | 673 | 7426·4 | 11·8 | 742 | 8203·6 | 10·7 |
| 536 | 5613·8 | 14·9 | 605 | 6578·2 | 13·1 | 674 | 7438·2 | 11·8 | 743 | 8214·3 | 10·7 |
| 537 | 5628·7 | 14·8 | 606 | 6591·3 | 13·1 | 675 | 7450·0 | 11·8 | 744 | 8225·0 | 10·7 |
| 538 | 5643·5 | 14·8 | 607 | 6604·4 | 13·1 | 676 | 7461·8 | 11·8 | 745 | 8235·7 | 10·7 |
| 539 | 5658·3 | 14·7 | 608 | 6617·5 | 13·1 | 677 | 7473·6 | 11·7 | 746 | 8246·4 | 10·7 |
| 540 | 5673·0 | 14·8 | 609 | 6630·6 | 13·1 | 678 | 7485·3 | 11·7 | 747 | 8257·1 | 10·6 |
| 541 | 5687·8 | 14·7 | 610 | 6643·7 | 13·0 | 679 | 7497·0 | 11·7 | 748 | 8267·7 | 10·7 |
| 542 | 5702·5 | 14·7 | 611 | 6656·7 | 13·0 | 680 | 7508·7 | 11·7 | 749 | 8278·4 | 10·6 |
| 543 | 5717·2 | 14·6 | 612 | 6669·7 | 13·0 | 681 | 7520·4 | 11·7 | 750 | 8289·0 | 10·6 |
| 544 | 5731·8 | 14·6 | 613 | 6682·7 | 13·0 | 682 | 7532·1 | 11·7 | 751 | 8299·6 | 10·6 |
| 545 | 5746·4 | 14·6 | 614 | 6695·7 | 13·0 | 683 | 7543·8 | 11·7 | 752 | 8310·2 | 10·6 |
| 546 | 5761·0 | 14·6 | 615 | 6708·7 | 12·9 | 684 | 7555·5 | 11·6 | 753 | 8320·8 | 10·6 |
| 547 | 5775·6 | 14·6 | 616 | 6721·6 | 12·9 | 685 | 7567·1 | 11·6 | 754 | 8331·4 | 10·5 |
| 548 | 5790·2 | 14·5 | 617 | 6734·5 | 12·9 | 686 | 7578·7 | 11·6 | 755 | 8341·9 | 10·5 |
| 549 | 5804·7 | 14·5 | 618 | 6747·4 | 12·9 | 687 | 7590·3 | 11·6 | 756 | 8352·4 | 10·6 |
| 550 | 5819·2 | 14·4 | 619 | 6760·3 | 12·9 | 688 | 7601·9 | 11·6 | 757 | 8363·0 | 10·5 |
| 551 | 5833·6 | 14·5 | 620 | 6773·2 | 12·8 | 689 | 7613·5 | 11·5 | 758 | 8373·5 | 10·5 |
| 552 | 5848·1 | 14·4 | 621 | 6786·0 | 12·8 | 690 | 7625·0 | 11·5 | 759 | 8384·0 | 10·5 |
| 553 | 5862·5 | 14·4 | 622 | 6798·8 | 12·8 | 691 | 7636·5 | 11·5 | 760 | 8394·5 | 10·4 |
| 554 | 5876·9 | 14·3 | 623 | 6811·6 | 12·8 | 692 | 7648·0 | 11·5 | 761 | 8404·9 | 10·5 |
| 555 | 5891·2 | 14·4 | 624 | 6824·4 | 12·7 | 693 | 7659·5 | 11·5 | 762 | 8415·4 | 10·4 |
| 556 | 5905·6 | 14·3 | 625 | 6837·1 | 12·7 | 694 | 7671·0 | 11·5 | 763 | 8425·8 | 10·5 |
| 557 | 5919·9 | 14·3 | 626 | 6849·8 | 12·7 | 695 | 7682·5 | 11·5 | 764 | 8436·3 | 10·4 |
| 558 | 5934·2 | 14·2 | 627 | 6862·5 | 12·7 | 696 | 7694·0 | 11·4 | 765 | 8446·7 | 10·4 |
| 559 | 5948·4 | 14·2 | 628 | 6875·2 | 12·7 | 697 | 7705·4 | 11·4 | 766 | 8457·1 | 10·4 |
| 560 | 5962·6 | 14·2 | 629 | 6887·9 | 12·7 | 698 | 7716·8 | 11·4 | 767 | 8467·5 | 10·4 |
| 561 | 5976·8 | 14·2 | 630 | 6900·6 | 12·6 | 699 | 7728·2 | 11·4 | 768 | 8477·9 | 10·3 |
| 562 | 5991·0 | 14·1 | 631 | 6913·2 | 12·6 | 700 | 7739·6 | 11·4 | 769 | 8488·2 | 10·4 |
| 563 | 6005·1 | 14·2 | 632 | 6925·8 | 12·6 | 701 | 7751·0 | 11·3 | 770 | 8498·6 | 10·3 |
| 564 | 6019·3 | 14·1 | 633 | 6938·4 | 12·6 | 702 | 7762·3 | 11·3 | 771 | 8508·9 | 10·3 |
| 565 | 6033·4 | 14·1 | 634 | 6951·0 | 12·5 | 703 | 7773·6 | 11·3 | 772 | 8519·2 | 10·3 |
| 566 | 6047·5 | 14·1 | 635 | 6963·5 | 12·6 | 704 | 7784·9 | 11·3 | 773 | 8529·5 | 10·3 |
| 567 | 6061·6 | 14·0 | 636 | 6976·1 | 12·5 | 705 | 7796·2 | 11·3 | 774 | 8639·8 | 10·3 |
| 568 | 6075·6 | 14·0 | 637 | 6988·6 | 12·5 | 706 | 7807·5 | 11·3 | 775 | 8550·1 | 10·3 |
| 569 | 6089·6 | 14·0 | 638 | 7001·1 | 12·4 | 707 | 7818·8 | 11·3 | 776 | 8560·4 | 10·2 |
| 570 | 6103·6 | 14·0 | 639 | 7013·5 | 12·5 | 708 | 7830·1 | 11·2 | 777 | 8570·6 | 10·3 |
| 571 | 6117·6 | 13·9 | 640 | 7026·0 | 12·4 | 709 | 7841·3 | 11·2 | 778 | 8580·9 | 10·2 |
| 572 | 6131·5 | 13·9 | 641 | 7038·4 | 12·4 | 710 | 7852·5 | 11·2 | 779 | 8591·1 | 10·2 |
| 573 | 6145·4 | 13·9 | 642 | 7050·8 | 12·4 | 711 | 7863·7 | 11·2 | 780 | 8601·3 | 10·2 |
| 574 | 6159·3 | 13·8 | 643 | 7063·2 | 12·4 | 712 | 7874·9 | 11·2 | 781 | 8611·5 | 10·2 |
| 575 | 6173·1 | 13·9 | 644 | 7075·6 | 12·4 | 713 | 7886·1 | 11·2 | 782 | 8621·7 | 10·2 |
| 576 | 6187·0 | 13·8 | 645 | 7088·0 | 12·3 | 714 | 7897·3 | 11·1 | 783 | 8631·9 | 10·1 |
| 577 | 6200·8 | 13·8 | 646 | 7100·3 | 12·3 | 715 | 7908·4 | 11·2 | 784 | 8642·0 | 10·2 |
| 578 | 6214·6 | 13·8 | 647 | 7112·6 | 12·3 | 716 | 7919·6 | 11·1 | 785 | 8652·2 | 10·1 |
| 579 | 6228·4 | 13·8 | 648 | 7124·9 | 12·3 | 717 | 7930·7 | 11·1 | 786 | 8662·3 | 10·2 |
| 580 | 6242·1 | 13·7 | 649 | 7137·2 | 12·3 | 718 | 7941·8 | 11·1 | 787 | 8672·5 | 10·1 |
| 581 | 6255·8 | 13·7 | 650 | 7149·5 | 12·2 | 719 | 7952·9 | 11·0 | 788 | 8682·6 | 10·1 |
| 582 | 6269·5 | 13·7 | 651 | 7161·7 | 12·2 | 720 | 7963·9 | 11·1 | 789 | 8692·7 | 10·1 |
| 583 | 6283·2 | 13·6 | 652 | 7173·9 | 12·2 | 721 | 7975·0 | 11·0 | 790 | 8702·8 | 10·0 |
| 584 | 6296·8 | 13·6 | 653 | 7186·1 | 12·2 | 722 | 7986·0 | 11·0 | 791 | 8712·8 | 10·1 |
| 585 | 6310·4 | 13·6 | 654 | 7198·3 | 12·2 | 723 | 7997·0 | 11·0 | 792 | 8722·9 | 10·0 |
| 586 | 6324·0 | 13·6 | 655 | 7210·5 | 12·1 | 724 | 8008·0 | 11·0 | 793 | 8732·9 | 10·1 |
| 587 | 6337·6 | 13·6 | 656 | 7222·6 | 12·1 | 725 | 8019·0 | 11·0 | 794 | 8743·0 | 10·0 |
| 588 | 6351·2 | 13·5 | 657 | 7234·7 | 12·1 | 726 | 8030·0 | 11·0 | 795 | 8753·0 | 10·0 |
| 589 | 6364·7 | 13·5 | 658 | 7246·8 | 12·1 | 727 | 8041·0 | 10·9 | 796 | 8763·0 | 10·0 |
| 590 | 6378·2 | 13·5 | 659 | 7258·9 | 12·1 | 728 | 8051·9 | 10·9 | 797 | 8773·0 | 10·0 |
| 591 | 6391·7 | 13·5 | 660 | 7271·0 | 12·1 | 729 | 8062·8 | 10·9 | 798 | 8783·0 | 10 0 |
| 592 | 6405·2 | 13·4 | 661 | 7283·1 | 12·1 | 730 | 8073·7 | 10·9 | 799 | 8793·0 | 9·9 |
| 593 | 6418·6 | 13·4 | 662 | 7295·1 | 12·0 | 731 | 8084·6 | 10·9 | 800 | 8802·9 | 9·9 |
| 594 | 6432·0 | | 663 | 7307·1 | | 732 | 8095·5 | | 801 | 8812·8 | |

TABLE II.—Correction; $-1^{m}\cdot2843\ (T-T')$.

| T − T′. | Correction. | T − T′. | Correction. | T − T′. | Correction. | T − T′. | Correction. | T − T′. | Correction. | T − T′. | Correction. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | m. | ° | m. | ° | m. | ° | m. | ° | m. | ° | m. |
| 0·0 | 0·0 | 4·2 | 5·4 | 8·2 | 10·5 | 12·2 | 15·7 | 16·2 | 20·8 | 20·2 | 25·9 |
| 0·2 | 0·3 | 4·4 | 5·7 | 8·4 | 10·8 | 12·4 | 15·9 | 16·4 | 21·1 | 20·4 | 26·2 |
| 0·4 | 0·5 | 4·6 | 5·9 | 8·6 | 11·0 | 12·6 | 16·2 | 16·6 | 21·3 | 20·6 | 26·5 |
| 0·6 | 0·8 | 4·8 | 6·2 | 8·8 | 11·3 | 12·8 | 16·4 | 16·8 | 21·6 | 20·8 | 26·7 |
| 0·8 | 1·0 | 5·0 | 6·4 | 9·0 | 11·6 | 13·0 | 16·7 | 17·0 | 21·8 | 21·0 | 27·0 |
| 1·0 | 1·3 | 5·2 | 6·7 | 9·2 | 11·8 | 13·2 | 17·0 | 17·2 | 22·1 | 21·2 | 27·2 |
| 1·2 | 1·5 | 5·4 | 6·9 | 9·4 | 12·1 | 13·4 | 17·2 | 17·4 | 22·3 | 21·4 | 27·5 |
| 1·4 | 1·8 | 5·6 | 7·2 | 9·6 | 12·3 | 13·6 | 17·5 | 17·6 | 22·6 | 21·6 | 27·7 |
| 1·6 | 2·1 | 5·8 | 7·4 | 9·8 | 12·6 | 13·8 | 17·7 | 17·8 | 22·9 | 21·8 | 28·0 |
| 1·8 | 2·3 | 6·0 | 7·7 | 10·0 | 12·8 | 14·0 | 18·0 | 18·0 | 23·1 | 22·0 | 28·3 |
| 2·0 | 2·6 | 6·2 | 8·0 | 10·2 | 13·1 | 14·2 | 18·2 | 18·2 | 23·4 | 22·2 | 28·5 |
| 2·2 | 2·8 | 6·4 | 8·2 | 10·4 | 13·4 | 14·4 | 18·5 | 18·4 | 23·6 | 22·4 | 28·8 |
| 2·4 | 3·1 | 6·6 | 8·5 | 10·6 | 13·6 | 14·6 | 18·8 | 18·6 | 23·9 | 22·6 | 29·0 |
| 2·6 | 3·3 | 6·8 | 8·7 | 10·8 | 13·9 | 14·8 | 19·0 | 18·8 | 24·1 | 22·8 | 29·3 |
| 2·8 | 3·6 | 7·0 | 9·0 | 11·0 | 14·1 | 15·0 | 19·3 | 19·0 | 24·4 | 23·0 | 29·5 |
| 3·0 | 3·9 | 7·2 | 9·2 | 11·2 | 14·4 | 15·2 | 19·5 | 19·2 | 24·7 | 23·2 | 29·8 |
| 3·2 | 4·1 | 7·4 | 9·5 | 11·4 | 14·6 | 15·4 | 19·8 | 19·4 | 24·9 | 23·4 | 30·1 |
| 3·4 | 4·4 | 7·6 | 9·8 | 11·6 | 14·9 | 15·6 | 20·0 | 19·6 | 25·2 | 23·6 | 30·3 |
| 3·6 | 4·6 | 7·8 | 10·0 | 11·8 | 15·2 | 15·8 | 20·3 | 19·8 | 25·4 | 23·8 | 30·6 |
| 3·8 | 4·9 | 8·0 | 10·3 | 12·0 | 15·4 | 16·0 | 20·5 | 20·0 | 25·7 | 24·0 | 30·8 |
| 4·0 | 5·1 | | | | | | | | | | |

The correction is subtracted when T − T′ is positive, and added when T − T′ is negative.

TABLE III.

Correction; $A\left\{\cdot00265\cos 2L + \frac{A+15926}{6366198}\right\}$; always to be added.

| Height approximating to A. | LATITUDE L. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0° | 3° | 6° | 9° | 12° | 15° | 18° | 21° | 24° | 27° | 30° |
| m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. |
| 100 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·4 | 0·4 | 0·4 | 0·4 |
| 200 | 1·0 | 1·0 | 1·0 | 1·0 | 1·0 | 1·0 | 0·9 | 0·9 | 0·9 | 0·8 | 0·8 |
| 300 | 1·6 | 1·6 | 1·6 | 1·5 | 1·5 | 1·5 | 1·4 | 1·4 | 1·3 | 1·2 | 1·2 |
| 400 | 2·1 | 2·1 | 2·1 | 2·0 | 2·0 | 1·9 | 1·9 | 1·8 | 1·7 | 1·7 | 1·6 |
| 500 | 2·6 | 2·6 | 2·6 | 2·5 | 2·5 | 2·4 | 2·4 | 2·3 | 2·2 | 2·1 | 2·0 |
| 600 | 3·2 | 3·1 | 3·1 | 3·1 | 3·0 | 2·9 | 2·8 | 2·7 | 2·6 | 2·5 | 2·4 |
| 700 | 3·7 | 3·7 | 3·6 | 3·6 | 3·5 | 3·4 | 3·3 | 3·2 | 3·1 | 2·9 | 2·7 |
| 800 | 4·2 | 4·2 | 4·2 | 4·1 | 4·0 | 3·9 | 3·8 | 3·7 | 3·5 | 3·3 | 3·2 |
| 900 | 4·8 | 4·8 | 4·7 | 4·6 | 4·6 | 4·5 | 4·3 | 4·1 | 4·0 | 3·8 | 3·6 |
| 1000 | 5·3 | 5·3 | 5·3 | 5·2 | 5·1 | 5·0 | 4·8 | 4·6 | 4·4 | 4·2 | 4·0 |
| 1100 | 5·9 | 5·8 | 5·8 | 5·7 | 5·6 | 5·5 | 5·3 | 5·1 | 4·9 | 4·7 | 4·4 |
| 1200 | 6·4 | 6·4 | 6·3 | 6·2 | 6·1 | 6·0 | 5·8 | 5·6 | 5·4 | 5·1 | 4·8 |
| 1300 | 7·0 | 6·9 | 6·9 | 6·8 | 6·7 | 6·5 | 6·3 | 6·1 | 5·8 | 5·5 | 5·2 |
| 1400 | 7·5 | 7·5 | 7·4 | 7·3 | 7·2 | 7·0 | 6·8 | 6·6 | 6·3 | 6·0 | 5·7 |
| 1500 | 8·1 | 8·1 | 8·0 | 7·9 | 7·7 | 7·5 | 7·3 | 7·1 | 6·8 | 6·4 | 6·1 |
| 1600 | 8·6 | 8·6 | 8·5 | 8·4 | 8·3 | 8·1 | 7·8 | 7·6 | 7·2 | 6·9 | 6·5 |
| 1700 | 9·2 | 9·2 | 9·1 | 9·0 | 8·8 | 8·6 | 8·4 | 8·1 | 7·7 | 7·4 | 7·0 |
| 1800 | 9·8 | 9·8 | 9·7 | 9·5 | 9·3 | 9·1 | 8·9 | 8·6 | 8·2 | 7·8 | 7·4 |
| 1900 | 10·4 | 10·3 | 10·2 | 10·1 | 9·9 | 9·7 | 9·4 | 9·1 | 8·7 | 8·3 | 7·8 |
| 2000 | 10·9 | 10·9 | 10·8 | 10·7 | 10·5 | 10·2 | 9·9 | 9·6 | 9·2 | 8·7 | 8·3 |
| 2100 | 11·5 | 11·5 | 11·4 | 11·2 | 11·0 | 10·8 | 10·4 | 10·1 | 9·7 | 9·2 | 8·8 |
| 2200 | 12·1 | 12·1 | 12·0 | 11·8 | 11·6 | 11·3 | 11·0 | 10·6 | 10·2 | 9·7 | 9·2 |
| 2300 | 12·7 | 12·6 | 12·5 | 12·4 | 12·1 | 11·8 | 11·5 | 11·1 | 10·7 | 10·2 | 9·6 |
| 2400 | 13·3 | 13·2 | 13·1 | 13·0 | 12·7 | 12·4 | 12·1 | 11·6 | 11·2 | 10·6 | 10·1 |
| 2500 | 13·9 | 13·8 | 13·7 | 13·5 | 13·3 | 13·0 | 12·6 | 12·2 | 11·7 | 11·1 | 10·5 |
| 2600 | 14·5 | 14·4 | 14·3 | 14·1 | 13·9 | 13·5 | 13·1 | 12·7 | 12·2 | 11·6 | 11·0 |
| 2700 | 15·1 | 15·0 | 14·9 | 14·7 | 14·4 | 14·1 | 13·7 | 13·2 | 12·7 | 12·2 | 11·5 |
| 2800 | 15·7 | 15·6 | 15·5 | 15·3 | 15·0 | 14·7 | 14·2 | 13·8 | 13·2 | 12·6 | 12·0 |
| 2900 | 16·3 | 16·2 | 16·1 | 15·9 | 15·6 | 15·2 | 14·8 | 14·3 | 13·7 | 13·0 | 12·3 |
| 3000 | 16·9 | 16·8 | 16·7 | 16·5 | 16·2 | 15·8 | 15·3 | 14·8 | 14·2 | 13·6 | 12·9 |
| 3500 | 20·0 | 19·9 | 19·8 | 19·5 | 19·2 | 18·7 | 18·2 | 17·6 | 16·9 | 16·1 | 15·3 |
| 4000 | 23·1 | 23·1 | 22·9 | 22·6 | 22·2 | 21·7 | 21·1 | 20·4 | 19·6 | 18·7 | 17·8 |
| 5000 | 29·7 | 29·6 | 29·4 | 29·0 | 28·5 | 27·9 | 27·2 | 26·3 | 25·3 | 24·2 | 23·1 |
| 6000 | 36·6 | 36·5 | 36·2 | 35·8 | 35·2 | 34·4 | 33·5 | 32·5 | 31·3 | 30·0 | 28·6 |
| 7000 | 43·8 | 43·7 | 43·4 | 42·9 | 42·2 | 41·3 | 40·2 | 39·0 | 37·6 | 36·1 | 34·5 |

TABLE III.—*continued.*

| Height approximating to A. | LATITUDE L. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 33° | 36° | 39° | 42° | 45° | 48° | 51° | 54° | 57° | 60° | 63° |
| m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. |
| 100 | 0·4 | 0·3 | 0·3 | 0·3 | 0·2 | 0·2 | 0·2 | 0·2 | 0·1 | 0·1 | 0·1 |
| 200 | 0·7 | 0·7 | 0·6 | 0·6 | 0·5 | 0·5 | 0·4 | 0·3 | 0·3 | 0·2 | 0·2 |
| 300 | 1·1 | 1·0 | 0·9 | 0·9 | 0·8 | 0·7 | 0·6 | 0·5 | 0·4 | 0·4 | 0·3 |
| 400 | 1·5 | 1·4 | 1·3 | 1·1 | 1·0 | 0·9 | 0·8 | 0·7 | 0·6 | 0·5 | 0·4 |
| 500 | 1·8 | 1·7 | 1·6 | 1·4 | 1·3 | 1·2 | 1·0 | 0·9 | 0·8 | 0·6 | 0·5 |
| 600 | 2·2 | 2·1 | 1·9 | 1·7 | 1·6 | 1·4 | 1·2 | 1·1 | 0·9 | 0·8 | 0·6 |
| 700 | 2·6 | 2·4 | 2·2 | 2·0 | 1·8 | 1·6 | 1·4 | 1·3 | 1·1 | 0·9 | 0·7 |
| 800 | 3·0 | 2·8 | 2·5 | 2·3 | 2·1 | 1·9 | 1·7 | 1·4 | 1·2 | 1·0 | 0·9 |
| 900 | 3·4 | 3·1 | 2·9 | 2·7 | 2·4 | 2·1 | 1·9 | 1·6 | 1·4 | 1·2 | 1·0 |
| 1000 | 3·7 | 3·5 | 3·2 | 2·9 | 2·7 | 2·4 | 2·1 | 1·8 | 1·6 | 1·3 | 1·1 |
| 1100 | 4·1 | 3·8 | 3·5 | 3·2 | 2·9 | 2·6 | 2·3 | 2·0 | 1·8 | 1·5 | 1·2 |
| 1200 | 4·5 | 4·2 | 3·9 | 3·6 | 3·2 | 2·9 | 2·6 | 2·2 | 1·9 | 1·6 | 1·4 |
| 1300 | 4·9 | 4·6 | 4·2 | 3·9 | 3·5 | 3·2 | 2·8 | 2·5 | 2·1 | 1·8 | 1·5 |
| 1400 | 5·3 | 5·0 | 4·6 | 4·2 | 3·8 | 3·4 | 3·0 | 2·7 | 2·3 | 1·9 | 1·6 |
| 1500 | 5·7 | 5·3 | 4·9 | 4·5 | 4·1 | 3·7 | 3·3 | 2·9 | 2·5 | 2·1 | 1·8 |
| 1600 | 6·1 | 5·7 | 5·3 | 4·9 | 4·4 | 4·0 | 3·5 | 3·1 | 2·7 | 2·3 | 1·9 |
| 1700 | 6·5 | 6·1 | 5·6 | 5·2 | 4·7 | 4·2 | 3·8 | 3·3 | 2·9 | 2·5 | 2·1 |
| 1800 | 7·0 | 6·5 | 6·0 | 5·5 | 5·0 | 4·5 | 4·0 | 3·5 | 3·1 | 2·6 | 2·2 |
| 1900 | 7·4 | 6·9 | 6·4 | 5·8 | 5·3 | 4·8 | 4·3 | 3·8 | 3·3 | 2·8 | 2·4 |
| 2000 | 7·8 | 7·3 | 6·7 | 6·2 | 5·6 | 5·1 | 4·5 | 4·0 | 3·5 | 3·0 | 2·5 |
| 2100 | 8·2 | 7·7 | 7·1 | 6·5 | 5·9 | 5·4 | 4·8 | 4·2 | 3·7 | 3·2 | 2·7 |
| 2200 | 8·6 | 8·1 | 7·5 | 6·9 | 6·3 | 5·7 | 5·0 | 4·5 | 3·9 | 3·3 | 2·8 |
| 2300 | 9·1 | 8·5 | 7·8 | 7·2 | 6·6 | 5·9 | 5·3 | 4·7 | 4·1 | 3·5 | 3·0 |
| 2400 | 9·5 | 8·9 | 8·2 | 7·6 | 6·9 | 6·3 | 5·7 | 5·1 | 4·3 | 3·7 | 3·2 |
| 2500 | 9·9 | 9·2 | 8·6 | 7·9 | 7·2 | 6·5 | 5·9 | 5·2 | 4·5 | 3·9 | 3·3 |
| 2600 | 10·4 | 9·7 | 9·0 | 8·3 | 7·6 | 6·8 | 6·1 | 5·4 | 4·8 | 4·1 | 3·5 |
| 2700 | 10·8 | 10·1 | 9·4 | 8·6 | 7·9 | 7·1 | 6·4 | 5·7 | 5·0 | 4·3 | 3·7 |
| 2800 | 11·3 | 10·5 | 9·8 | 9·0 | 8·2 | 7·5 | 6·7 | 5·9 | 5·2 | 4·5 | 3·9 |
| 2900 | 11·7 | 11·0 | 10·2 | 9·4 | 8·6 | 7·8 | 7·0 | 6·2 | 5·5 | 4·7 | 4·1 |
| 3000 | 12·2 | 11·4 | 10·6 | 9·8 | 8·9 | 8·1 | 7·3 | 6·5 | 5·7 | 4·9 | 4·2 |
| 3500 | 14·4 | 13·5 | 12·6 | 11·6 | 10·7 | 9·7 | 8·8 | 7·8 | 6·9 | 6·0 | 5·2 |
| 4000 | 16·8 | 15·8 | 14·7 | 13·6 | 12·5 | 11·4 | 10·3 | 9·2 | 8·2 | 7·2 | 6·3 |
| 5000 | 21·8 | 20·5 | 19·2 | 17·8 | 16·4 | 15·0 | 13·7 | 12·3 | 11·0 | 9·8 | 8·7 |
| 6000 | 27·1 | 25·6 | 24·0 | 22·3 | 20·7 | 19·0 | 17·4 | 15·8 | 14·2 | 12·7 | 11·3 |
| 7000 | 32·8 | 30·9 | 29·1 | 27·1 | 25·2 | 23·3 | 21·4 | 19·5 | 17·7 | 15·9 | 14·3 |

TABLE IV.—Diminution of weight in the vertical due to the heights of the lower station.

Correction; $A\left(\cdot 00576 \log. \frac{760}{H}\right)$; always to be added.

| Height approximating to A. | HEIGHT OF BAROMETER AT LOWER STATION. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 460 | 490 | 520 | 550 | 580 | 610 | 640 | 670 | 700 | 730 |
| m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. |
| 100 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·0 | 0·0 | 0·0 | 0·0 |
| 200 | 0·3 | 0·2 | 0·2 | 0·2 | 0·1 | 0·1 | 0·1 | 0·1 | 0·0 | 0·0 |
| 300 | 0·4 | 0·3 | 0·3 | 0·2 | 0·2 | 0·2 | 0·1 | 0·1 | 0·1 | 0·0 |
| 400 | 0·5 | 0·4 | 0·4 | 0·3 | 0·3 | 0·2 | 0·2 | 0·1 | 0·1 | 0·0 |
| 500 | 0·6 | 0·5 | 0·5 | 0·4 | 0·3 | 0·3 | 0·2 | 0·2 | 0·1 | 0·1 |
| 600 | 0·8 | 0·7 | 0·6 | 0·5 | 0·4 | 0·3 | 0·3 | 0·2 | 0·1 | 0·1 |
| 700 | 0·9 | 0·8 | 0·7 | 0·6 | 0·5 | 0·4 | 0·3 | 0·2 | 0·1 | 0·1 |
| 800 | 1·0 | 0·9 | 0·8 | 0·6 | 0·5 | 0·4 | 0·3 | 0·3 | 0·2 | 0·1 |
| 900 | 1·1 | 1·0 | 0·9 | 0·7 | 0·6 | 0·5 | 0·4 | 0·3 | 0·2 | 0·1 |
| 1000 | 1·3 | 1·1 | 0·9 | 0·8 | 0·7 | 0·6 | 0·4 | 0·3 | 0·2 | 0·1 |
| 1200 | 1·5 | 1·3 | 1·1 | 1·0 | 0·8 | 0·7 | 0·5 | 0·4 | 0·2 | 0·1 |
| 1400 | 1·8 | 1·5 | 1·3 | 1·1 | 0·9 | 0·8 | 0·6 | 0·4 | 0·3 | 0·1 |
| 1600 | 2·0 | 1·8 | 1·5 | 1·3 | 1·1 | 0·9 | 0·7 | 0·5 | 0·3 | 0·2 |
| 1800 | 2·3 | 2·0 | 1·7 | 1·5 | 1·2 | 1·0 | 0·8 | 0·6 | 0·4 | 0·2 |
| 2000 | 2·5 | 2·2 | 1·9 | 1·6 | 1·4 | 1·1 | 0·9 | 0·6 | 0·4 | 0·2 |
| 2200 | 2·8 | 2·4 | 2·1 | 1·8 | 1·5 | 1·2 | 0·9 | 0·7 | 0·5 | 0·2 |
| 2400 | 3·0 | 2·6 | 2·3 | 1·9 | 1·6 | 1·3 | 1·0 | 0·8 | 0·5 | 0·2 |
| 2600 | 3·3 | 2·9 | 2·5 | 2·1 | 1·8 | 1·4 | 1·1 | 0·8 | 0·5 | 0·3 |
| 2800 | 3·5 | 3·1 | 2·7 | 2·3 | 1·9 | 1·5 | 1·2 | 0·9 | 0·6 | 0·3 |
| 3000 | 3·8 | 3·3 | 2·8 | 2·4 | 2·0 | 1·6 | 1·3 | 0·9 | 0·6 | 0·3 |
| 4000 | 5·0 | 4·4 | 3·8 | 3·2 | 2·7 | 2·2 | 1·7 | 1·3 | 0·8 | 0·4 |
| 5000 | .. | 5·5 | 4·7 | 4·0 | 3·4 | 2·8 | 2·1 | 1·6 | 1·0 | 0·5 |
| 6000 | .. | .. | .. | 4·9 | 4·1 | 3·3 | 2·6 | 1·9 | 1·2 | 0·6 |
| 7000 | .. | .. | .. | .. | .. | .. | 3·0 | 2·2 | 1·4 | 0·7 |
| 8000 | .. | .. | .. | .. | .. | .. | .. | .. | 1·6 | 0·8 |

BARRACKS. Fr., *Casernes*; Ger., *Caserne*; Ital., *Caserne*; Span., *Casernas*.

*Barrack.*—The word barrack is probably derived from the Saxon *Parruc*, an enclosure, or from the Spanish *Barracas*, small huts for fishermen, and is the general term employed in this country for a building or collection of buildings of a permanent nature used for the residence of troops; while buildings of a less permanent kind, such as at Aldershot or the Curragh, we generally call camps. On the Continent, however, the term equivalent in sound to our barracks appears limited to huts or field-huts, while the more permanent buildings are called casernes, or caserme, derived, no doubt, from the Spanish or Italian. *Casa*, a house. The Germans generally have adopted the French term.

In the mediæval ages, and before standing armies formed a part of the institution of the country, soldiers were generally lodged in the different feudal or royal fortresses, which occupied the principal strong positions, both for offence and defence, throughout the kingdom; but after the Revolution, and more particularly in Ireland, where it was necessary to keep up a very numerous force, we begin to find large sums expended in the construction of buildings for the purposes of our modern barracks. In the reign of the first George, the Royal Barracks, Dublin, were thus erected, affording accommodation at that period for perhaps 5000 men, on an area of about 14 acres, although, owing to the enlarged cubical space now allotted to each soldier, they will accommodate no more than 1800. Few, therefore, if any of our barracks present any archæological interest extending further back than the middle or latter end of the last century, if we except the generally incongruous alterations effected in some of our old fortresses to accommodate our soldiers, such as those in Edinburgh and Stirling Castles, the Tower, Dover Castle, Yarmouth, &c., &c. The officers' quarters at Dover Castle are a creditable adaptation of the architecture of the existing buildings. A very good idea of what military lodging in the middle ages was, may be obtained by inspecting the lower stories of Roslin Castle, the keep at Newcastle, and other *souterraines* of castles of that period.

With the exception of a few on a large scale, built during the last century, or in the early part of the present one—such as those of Dublin, Cork, and Fermoy, in Ireland: the cavalry barracks of Piershill, near Edinburgh; those of York and Canterbury—the greater part of our barracks were composed of mere makeshifts, many of them in the heart of large towns, cribbed and confined in space, overcrowded, and quite devoid of any sanitary arrangements, drainage, or even a proper supply of water.

It was not until the General Report of the Commission appointed for improving the Sanitary Condition of Barracks and Hospitals appeared in 1861, that any idea could be formed of the real state of the existing dwellings of the British army in the United Kingdom, extending in number to 243 distinct barracks, and 167 hospitals. Many of them are described as being built in densely-peopled neighbourhoods, and closely surrounded by dwellings of the civil population, often of the very lowest classes. Some of the Metropolitan barracks, such as St. George's, behind the National Gallery, and Portman Barracks, are especially notorious in this respect, and also many of those in Portsmouth; Knightsbridge Barrack is also specially condemned. In numerous cases, existing barracks consist of blocks of private buildings, or ordinary dwelling-houses, often in low neighbourhoods, in which, owing to political or other causes, it was at some period deemed desirable to station troops, such as the Ship Street and Linen Hall Barracks in Dublin, the barracks in Cashel, Galway, and many other towns in Ireland, and in the manufacturing districts in England and Scotland. In such cases, no sanitary improvements short of entire demolition and reconstruction can ever afford accommodation adequate to what modern hygiene would require. Even in more recent times, when money has not been spared, and it would be naturally supposed the faults of older buildings would be avoided, our barrack architects or engineers have not been more successful—witness, the Guards' Barracks in St. James's Park, the new barracks in the Tower and in Edinburgh Castle, the Cavalry Barracks, Hounslow, and many others we could mention. As the unit of 600 cub. ft. space a man is now generally adopted as the minimum for barrack accommodation, it will be sufficient to state, that when the late Commission inspected the barracks of the United Kingdom, they found under the existing regulations provision made for 75,800 men, giving each a cubic space varying from 290 ft. to 550 ft. a man; while at the rate of 600 ft. a man, only 53,800 could be accommodated, showing a deficiency of barrack room for 22,000 men. In the Chatham district alone, 100 men were accommodated in the space sufficient only for 57.

The Barrack Commissioners, however, do not involve all existing barracks under a sentence of condemnation. Some of the block arrangements of the Irish barracks, especially those of Parsonstown, Templemore, Naas, Dundalk, Island Bridge, and Beggars' Bush Barracks, near Dublin, are commended, as well as the more modern barracks at Bury and Ashton, in Lancashire, and York Cavalry Barracks.

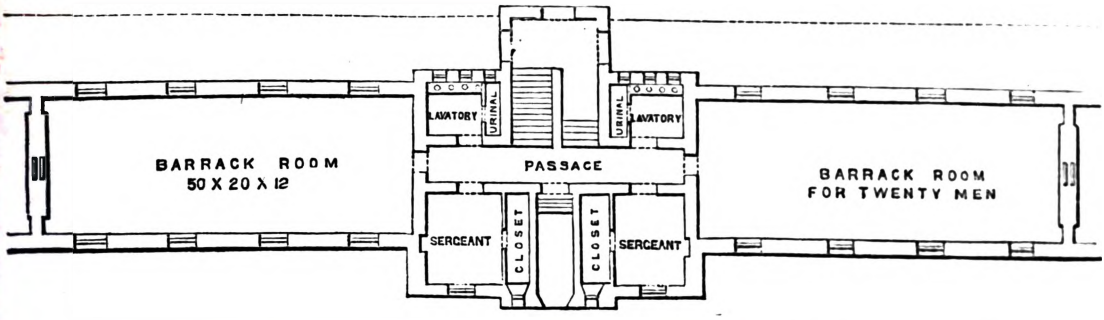
The recommendation of the Commission generally as to drainage, warming, water-supply, ablution, and other sanitary arrangements, have been gradually carried out wherever possible during the last seven or eight years, although, from economical motives connected with the War Department administration, much remains yet to be done.

The most recently built and improved barrack in London is that of Chelsea, near the Royal Hospital, constructed for a battalion of the Guards, from the designs of G. Morgan, who obtained the appointment of architect by public competition in 1858–9. It possesses all the required necessaries and accessories for modern military dwellings, including gymnasium, married soldiers' barracks, chapel, provost, stores, hospital, and so on, and cost on the whole a sum of 296,000*l*., or about 245*l*. a head, including all ranks; but which sum included the purchase of a very expensive site.

The subjoined sketch, Fig. 554, shows two units of barrack-rooms, complete, with the passage between them, or one floor of a barrack-house, in the new Chelsea Barracks. Each house, as it consisted of two or three floors, would contain four or six units, to accommodate twenty men each.

Chelsea Barracks consist simply of a number of units such as those shown in Fig. 554, extending in a straight line of about 1000 ft. in length, with a detached building for the staff-officers at one end, and for the staff-sergeants at the other. In the rear are placed the miscellaneous buildings.

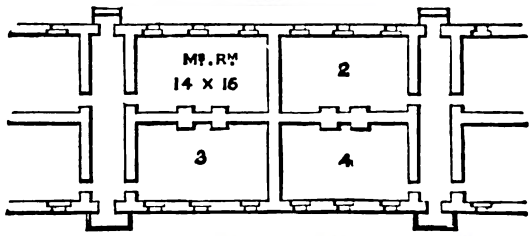
554.




The synopsis, given page 247, shows the different buildings deemed necessary for the accommodation of a battalion of infantry 1200 strong.

*Married Soldiers' Quarters.*—During the last few years, quarters for married soldiers, Fig. 555, affording one room of about 220 superficial area to each married soldier, or about 6 per cent. on the regimental strength, have been built at the principal barracks in the United Kingdom, with all necessary out-offices, washing and ablution rooms, at a cost of about 180*l.* each man.

555.




Ground-plan of Married Soldiers' Quarters.

*Constructive Elements of Healthy Barrack-rooms.*—The elements of healthy barrack-room construction are :—

1. Accommodation for 20 to 30 beds in each room, at 600 cub. ft. per head.
2. Height of room, 11 to 12 ft.
3. Breadth of room, 19 to 20 ft.
4. Windows equal to one-half the number of beds, arranged on opposite sides of the room.
5. No more than two rows of beds in each room; and 5 ft. in breadth, at least, allowed for each bed.
6. No barrack-room to contain a sergeant's bunk.

Each barrack-room should have a sergeant's room opening from the landing or passage and connected with the barrack-room, and opposite the entrance, there should be a well-lighted and ventilated lavatory, with fixed ablution-basins, and proper water-service laid on. One basin will be sufficient for every ten men. In the same room should be placed a night-urinal.

The barrack-room unit would then consist of (1) barrack-room, (2) sergeant's room, (3) ablution-room, (4) night-urinal; and a barrack would consist of a number of these units arranged as the available space may allow.

*Lighting.*—Home barracks are now generally lighted with gas, except in very remote situations. No gas, at the public expense, is allowed for officers' quarters, except for the mess establishment and passages. Gas-lights, when properly arranged, afford great facilities for the improvement of the ventilation of soldiers' rooms.

*Articles of Regulation-pattern, &c.*—To ensure uniformity as well as economy, articles of regulation-pattern, such as iron shelving, skirting, latrines, and ablution apparatus, ash bins, sinks, cooking apparatus of every kind, wash-house fitments, urinals, and so on, are now used generally both in construction and repair of all barracks in the United Kingdom, as well as those in the Colonies when circumstances will admit. Rules are also laid down for the thickness of floors description of doors, gates, &c., to be used generally. The external painting of barracks is performed every four, and the internal every seven years.

Although the majority of our barracks have been constructed without any regard to their defence in case of attack by a mob or insurrectionary body, yet, within the last few years, it is laid down as a general rule that they should be sufficiently fortified, by loop-holed flanking defences or otherwise, to resist a *coup de main* at least. Many of the Irish barracks are so constructed, and those at Ashton and Bury, in Lancashire, have flanking defences at the angles. On the other hand, we find many barracks so commanded by surrounding buildings, as to be hopelessly untenable in case of a resolute attack.

In addition to the buildings themselves, the War Department provides the necessary articles of furniture, bedding, and cooking utensils for all soldiers' and non-commissioned officers' quarters. For officers' quarters, large fixtures only, such as presses, kitchen tables and dressers, racks and pins, curtain-cornices, and so on, are provided at the public expense. All wilful damage committed by the occupants must be made good by them without cost to the public.

*Maintenance.*—Both the designing and repairs of all barracks are now carried on under the supervision of the Director of Works, who has under him the officers of the corps of Royal Engineers and the Civil Branch of Royal Engineers' Department. Formerly there was a Board

of Commissioners for Barracks, but their office was abolished by the late Duke of Wellington in 1818, when Master-General of the Ordnance, and their duties transferred to the corps of Royal Engineers. An officer named barrack-master is placed in local supervision and charge of all our principal barracks.

| | |
|---|---|
| The total sum voted for the construction and repairs of barrack buildings in the United Kingdom, for the year ending 31st March, 1869, was .. | £319,229 |
| For those in the Colonies .. .. .. .. .. .. .. .. .. .. .. | 142,905 |
| Total .. .. .. | £462,134 |

*Faulty Construction.*—The principal faults in the construction of existing barracks are those of site, defective drainage, and ventilation; the crowding of the blocks of buildings too close on each other, or piling floors too high; back-to-back barrack-rooms with windows only on one side, as in the Wellington Barracks and Edinburgh Castle, are especially condemned; also long, narrow, dark corridors, as in Hounslow Barracks; defective water-supply and the use of wells generally; and placing the soldiers' rooms over the stables, as is the case in too many modern cavalry barracks.

*Approved Construction.*—The approved construction of a barrack may be comprised in a few words. It should be as simple, yet as durable as possible; the walls built hollow, to preserve the rooms from damp, and the spaces under the floors properly ventilated; the floors and stair-cases to be fire-proof, the former constructed of wrought-iron joists, bedded in concrete, and the latter on as easy inclines as possible. Provision should be made for collecting the rain-water falling on roofs, which is always valuable for washing and cooking purposes. The site should have sufficient elevation to afford easy drainage, and every care should be taken to make all parades and exercising-grounds as solid and dry as possible. Fresh air, warmed by proper stoves, should be introduced into each room, so as to keep the temperature as near as possible steady to 60° Fahr.; while up-cast shafts, to remove all foul air, should be formed from each room at opposite corners. The latrines, urinals, ablution-rooms, and baths, should be plentifully supplied with water laid on with a proper head of pressure, either by direct service or from tanks or cisterns placed at a proper height. The introduction of wrought and cast iron in joists, sashes, &c., recommended wherever possible, as the wear and tear of material in barracks is enormous. The floors should be of wood, but those of ablution and bath rooms of asphalte; and of cook-houses, &c., flagging or tiles of a durable nature.

### Regimental Hospital Establishment.

[*Part of the tabulated arrangement, page* 247.]

7 per cent. to be provided on barrack accommodation.
1200 ft. of cubic space a bed, and 80 to 100 sq. ft. a bed.

*Ground Floor.*

| | Feet. | | Feet. |
|---|---|---|---|
| Wards:—No. 2 large | 1020 × 26 × 14 | No. 2 nurses' rooms .. .. | 11 × 9.4 |
| „ small .. | 20 × 13 | Surgery .. .. .. .. .. | 18 × 11 |
| Waiting-room .. .. .. | 18 × 11 | Scullery .. .. .. .. .. | 11 × 9 |
| Day-room .. .. .. .. | 18 × 15 | Water-closets, sinks, &c. | |

*First Floor.*

| | | | |
|---|---|---|---|
| Orderlies' room .. .. .. | 26.9 × 18 | Clean-linen store .. .. .. | 20 × 13 |
| Lavatory .. .. .. .. | 8 × 5 | Bedding-store .. .. .. | 15 × 10 |
| Water-closet and urinal. | | Pack-store .. .. .. .. | 18 × 11 |

*Kitchen Building.*

| | |
|---|---|
| Quarters for hospital-sergeant and steward, one room each .. .. .. .. | 20 × 13 |
| Kitchen .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. | 15 × 14 |
| Scullery and beer-cellar<br>Cook's room .. .. ..<br>Room for medical comforts<br>Larder .. .. .. .. | .. .. .. .. .. .. .. .. .. .. | Size according to available space. |

*Yard.*

| | Feet. | | Feet. |
|---|---|---|---|
| Foul-bedding store .. .. | 10 × 8 | Dead-house .. .. .. .. | 12 × 12 |
| Coal and wood stores .. | 10 × 8 | No. 4 latrines. | |
| Wash-house and laundry, each | 14 × 16 | „ urinals. | |

*Cavalry Barracks.*—The general arrangements, and cubical space, for the officers and men, mess establishment, &c., of a barrack for a regiment of cavalry, do not differ much from the accommodation provided for an equal number of infantry. The open areas for parades, exercising-grounds, and the like, however, require to be larger.

In modern cavalry barracks several important sanitary improvements have been recently made. In many of the older existing barracks, including Knightsbridge, Regent's Park, Hounslow, Hampton Court, Brighton, York Old Barracks, Hulme, Preston, Sheffield, Canterbury, Piershill near Edinburgh, Dublin Royal Barracks, Island Bridge, and several others, the men's rooms are situated over the stables, an arrangement which possesses some conveniences, but which is strongly condemned in the Report of the Barrack Commission of 1861. We may mention among cavalry barracks in which this objectionable arrangement does not exist, those of Dundalk, see Fig. 556, which is one of the best of all our cavalry barracks; Newbridge, near the Curragh Camp; Cahir; the New York Barracks; Maidstone, and other places.

## Synopsis of a Barrack to contain a Battalion of Infantry 1200 Strong, or 12 Companies.

| | | | | |
|---|---|---|---|---|
| 1 Lieut.-colonel. | 1 Paymaster. | 7 Staff-sergeants, Class A. | 50 Corporals. | 1 Mess-man. |
| 2 Majors. | 1 Adjutant. | 19 ,, ,, ,, B. | 76 Married Soldiers. | 1 Mess-waiter. |
| 12 Captains. | 1 Quartermaster. | 23 Married Sergeants. | 874 Privates. | 1 Cook. |
| 14 Lieutenants | 1 Surgeon. | 12 Single ,, | 1 Canteen Sergeant | 2 Com. Officers' Servants. |
| 10 Ensigns. | 1 Assistant-surgeon. | 24 Drummers. | 1 Librarian. | Stabling for 8 horses. |

### ACCOMMODATION.

**(1) Commanding Officers Quarters.**

| | Feet. |
|---|---|
| 2 Sitting-rooms | 20 × 18 |
| 2 Bed-rooms | 20 × 18 |
| 2 Servants' rooms | 16 × 15 |

Kitchen, scullery, larder, water-closets, and other out-offices.

**(2) Field Officers' Quarters.**

| | Feet. |
|---|---|
| 1 Sitting-room | 18 × 16 |
| 1 Bed-room | 18 × 16 |
| 1 Servant's room | 16 × 15 |

Water-closet, small yard, and out-house.

**(3) Officers' Quarters.**

| | Feet. |
|---|---|
| 1 Room each | 18 × 16 |
| Servant's room, for 2 officers | 18 × 16 |

Water-closets, 1 for 4 officers.
Sink.
Yard.
Out-house.
Latrine, 1 for 10 servants.

**(11) Regimental Stores.**

| | Feet. |
|---|---|
| Bread-store | 18 × 16 |
| Meat-store | 18 × 16 |
| Clothing-store | 35 × 18 |

Expense magazine.
Shifting-room.
Yard.

**(4) Mess Establishment.**

| | Feet. |
|---|---|
| Mess-room | 45 × 25 × 16 |
| Ante-room | 30 × 25 |
| ,, | 18 × 14 |
| ,, | 18 × 12 |

No. 3 water-closets.
Urinals and lavatory.
Mess-waiter's room
Pantry, wash-up room.
Plate-closet.
Wine-cellar and smaller offices at rear.

**(5) Mess-man's Quarters.**

| | Feet. |
|---|---|
| 2 Living-rooms | 18 × 16 |
| Store | 10 × 12 |
| Beer-cellar | 18 × 16 |
| Mess-kitchen | 25 × 20 |
| Scullery | 18 × 12 |
| Larder | 18 × 8 |

Coal-store.
Water-closet.
Latrine for servants.
Urinal.

**(6) Non-com. Officers' Quarters.**

| | Feet. |
|---|---|
| 1st class Staff-sergeant, 2 rooms | 16 × 14 |
| 2nd class ditto, 1 room | 16 × 14 |
| Water-closet, 1 on each floor, | |
| Sinks ,, | |
| Ablution-room for men | 10 × 10 |
| ,, ,, women | 10 × 10 |

Latrines and urinals.

**(7) Sergeants' Mess Establishment.**

| | Feet. |
|---|---|
| Mess-room | 40 × 20 × 13 |
| Store | 12 × 10 |
| Kitchen | 20 × 20 |
| Scullery | 15 × 12 |
| Larder | 15 × 7.6 |

Beer-cellar.
Coal-cellar.
Cook's living-room 20 × 15
Yard.
Latrines, No. 2.
Urinals, No. 2.
Shed 10 × 8

**(8) Married Soldiers' Quarters.**

| | Feet. |
|---|---|
| 1 Room each | 16 × 14 |

Water-closet and sink, 1 to each floor.
Men's ablution-room.
Women's ,,
4 Men's latrines.
4 Women's latrines.
6 Children's ,,
Urinals.
Yard.
Wash-house 46 × 20
Laundry 24 × 20
Bath-room 20 × 6
Drying-ground according to available space.

**(9) Soldiers' Barracks.**

| | Feet. |
|---|---|
| Non-com. officers' mess, 1 room | 14 × 14 |
| Soldiers' rooms, No. 38, for 34 men each | 70 × 20 × 12 |
| Ablution-rooms, No. 38 | 14 × 10 |
| Night-urinals, No. 38. | |
| Cook-houses, No. 2 | 40 × 20 × 14 |
| Latrines, No. 48 compartments. | |
| Urinals, No. 48. | |
| Bath-house, Non com. officers' | 17 × 5.6 |
| Bath-house, soldiers' | 27.6 × 17 |
| Attendant's room | 17 × 9 |
| Shed for tools | 20 × 10 |

**(10) Orderly, Guard Rooms, &c.**

| | Feet. |
|---|---|
| Orderly-room | 18 × 12 |
| Clerk's room | 24 × 18 |
| Paymaster's office | 18 × 14 |
| Guard-house | 21 × 18 |
| Guard-room cells, No. 5 | 10 × 8 |
| Prisoners' room | 24 × 18 |

Night-urinal.
Ablution-room.
No. 2 latrines.
No. 2 urinals.

| | Feet. |
|---|---|
| Armourer's shop | 13 × 13 |
| Armourer's store | 13 × 13 |
| Shoemaker's shop | 20 × 18 |
| Tailor's shop | 24 × 18 |
| Master tailor | 18 × 16 |

**Means of Recreation and Exercise.**

| | Feet. |
|---|---|
| Game-room | 65 × 30 × 16 |
| Reading-room | 50 × 30 |
| Library | 14 × 11.7 |
| Coffee-room | 16 × 12.6 |
| Lavatories | 16 × 8 |
| Librarian's room | 14 × 11.7 |
| 2 Bed-rooms | 14 × 11.7 |

Latrine, 3 compartments.
No. 2 urinals.

| | Feet. |
|---|---|
| No. 2 fives' courts | 55 × 30 |

Cricket-ground.
Skittle-ground.

| | Feet. |
|---|---|
| Gymnasium | 80 × 40 |
| Instructor's and dressing room | 15 × 12 |

Drill-ground, as space permits.
Drill-shed.
Practice-room for band 27 × 18

**Divine Worship.**

| | Feet. |
|---|---|
| Chapel school | 80 × 58 |
| Infant school | 25 × 15 |
| *Teacher's room | 14 × 11 |
| Bed-room | 14 × 11 |

Kitchen and offices.
Playground.
Schoolmasters' quarters as Staff-sergeants.
Latrines for boys and girls.

* Female.

**Canteen Establishment.**

| | Feet. |
|---|---|
| Canteen shop | 18 × 16 |
| ,, bar | 30 × 8 |
| ,, store | 16 × 10 |
| ,, cellar | 16 × 7 |
| ,, ,, No. 2 | 18 × 16 |
| Tap-room | 50 × 26 |
| No. 2 living-rooms for canteen-man | 16 × 14 |

Kitchen and scullery.
Yard.
Latrines and urinals.

**Cell Establishment.**

| | Feet. |
|---|---|
| (Proportion 2 per cent. on accommodation) | |
| No. 20 cells | 12 × 7.6 × 10 |

1 Sink and urinal on each floor.
1 Water-closet ditto.
Latrine in yard.

| | Feet. |
|---|---|
| Shed for shot-drill | 40 × 30 |
| Exercise shed | 50 × 10 |
| Kitchen | 16 × 14 |

Yard.
Provost-sergeant's quarters as for Class A.
Staff.
Coal-store.
Water-closet.

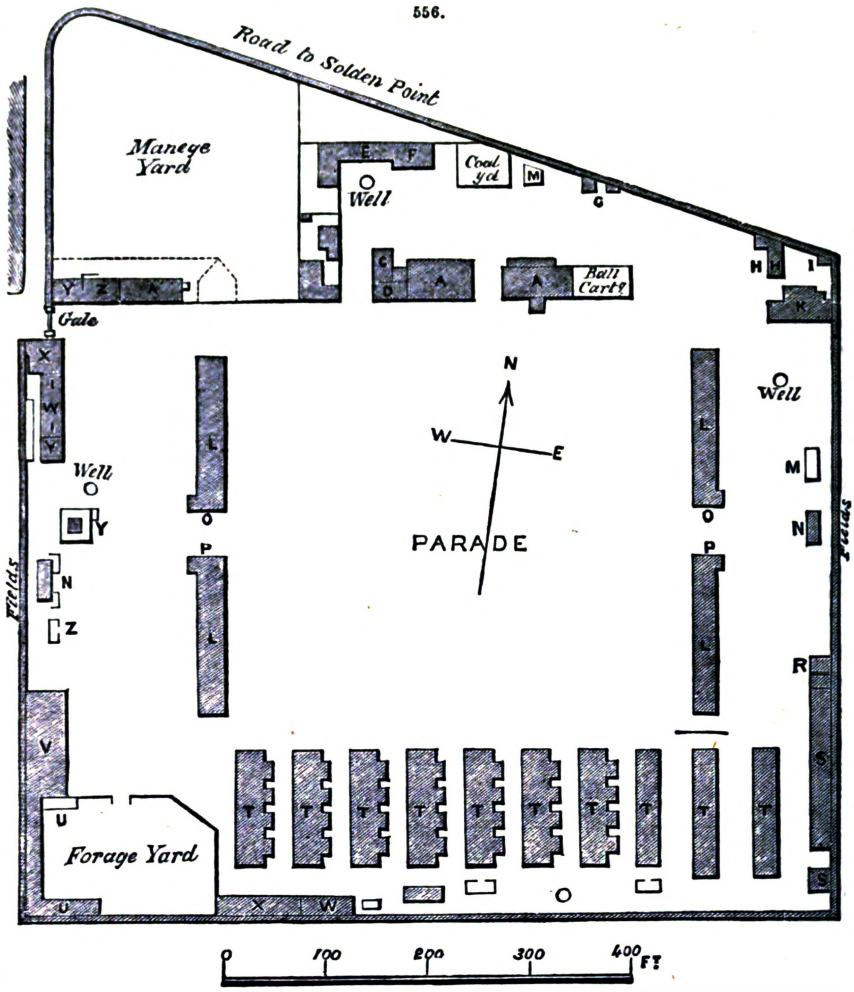
**Barrack-master's Establishment.**

| | Feet |
|---|---|
| Barrack office | 18 × 14 |
| Barrack-sergeants' quarters as Staff-sergeants. | |
| Foul-bedding store | 30 × 20 |
| Unserviceable stores | 33 × 20 |
| Meat-store | 30 × 20 |
| Coal-yard | 60 × 60 |
| Coal-shed | 60 × 30 |

Engine-house.
Ladder-shed.
Meter-house.
Latrine and urinal.
Hospital establishment. See *Hospital.*

The shelves and other fittings of cavalry barracks are nearly identical with those of infantry, except that some modification and provision must be made for racks for lances, swords, pistols, and carbines, with which the cavalry soldier is armed.

556.




Block-plan of Cavalry Barracks, Dundalk.

*References.*—*A*, Officers' quarters. *B*, Barrack-master's house. *C*, Bedding store. *E*, Barrack store. *F*, Straw store. *G*, Officers' privies. *H*, Hospital privy. *I*, Dead-house. *K*, Hospital. *L*, Soldiers' quarters. *M*, Ash-pits. *N*, Soldiers' privies. *O*, Cook-house. *P*, Wash-house and sheds. *R*, Armourer's shop. *S*, Infantry stables. *T*, Troop stables. *W*, Soldiers' wash-house. *X*, Forge and shop. *Y*, Magazine. *Z*, Dung-pits. *V'*, Engine-house. *W'*, Canteen. *X'*, Cells. *Y'*, Barrack-sergeants' quarters and cells. *Z'*, Guard-room and regimental store.

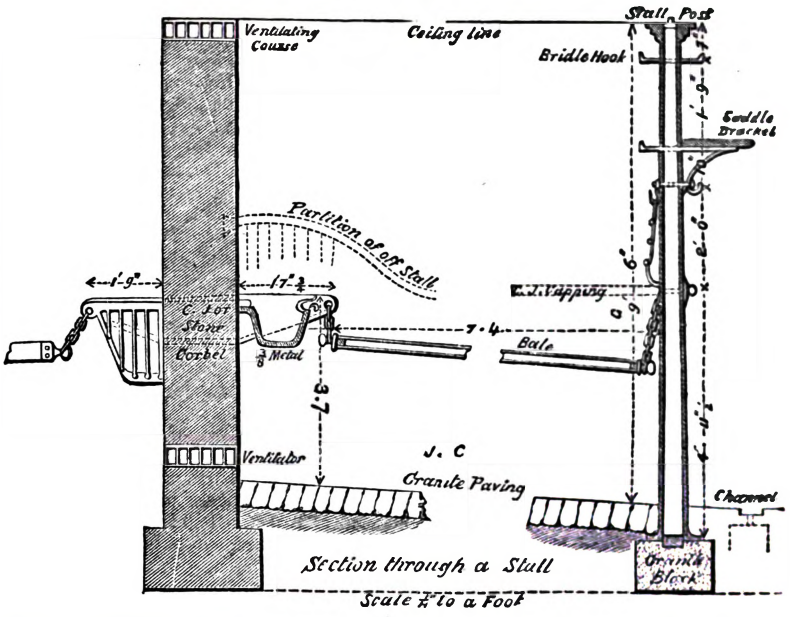
Cavalry stables, when they do not form a part of the range as above mentioned, are generally placed behind the main buildings, and are either built double, that is, with two rows of stalls and a passage between them, or single, with one row of stalls—in either case, the stall being considered as the unit. The cubical space allotted for each horse is about 1200 ft. The double stables have a width of 30 ft., the single 17 or 18 ft., with an average height of 10 ft. The size of the single stall averages 9 ft. 6 in. from the wall to outside of heel-post, and the width 5 ft. 7 in. The width of a stall for an officer's horse being 6 ft. Officers' stables have saddle-rooms, and separate hay and straw stores, with doors sufficiently large to admit a carriage. The stable accommodation provided for officers is that of the number of chargers they are entitled to draw forage for. Hospital or infirmary stables are also provided, in the proportion of 6 boxes and 14 stalls to every regiment, at the present establishment of 253 horses.

The drainage and ventilation of our cavalry stables are now carefully attended to. Ceilings to stables were formerly considered as indispensable, yet many are in favour of open roofs well ventilated at the ridge, and the under-side of rafters lathed and plastered to prevent the fall of dust. The stalls are generally paved with granite pitchers, 6 in. × 3 in., laid diagonally in Portland cement to a slope from front to rear of 1 in 80, and falling from the centre of stall to each side 1 in 40, with a dressed channel of stone or terra-cotta emptying into a trapped underground drain outside, and quite clear of stables. Local materials, however, in many cases, may be used.

The fitments of all cavalry stables are of cast and wrought iron, of a uniform established pattern, Figs. 557, 558, 559. The horses of the privates are separated by swing bales of hollowed wrought iron, 2¾ in. diam. The hay-racks and mangers are horizontal, supported by cast-iron or stone corbels built into walls. The use of the old-fashioned over-head hay-rack and wooden manger is discontinued in all military stables.

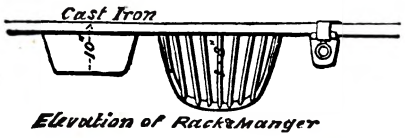
The walls of officers' stables are boarded to a height of 7 ft., and the stalls separated by 1½ in. tongued oak partitions, let into cast-iron capping and sole-pieces. The external doors are double, hung in two heights, and a swing window is provided for every stall in both single and double stables. A perforated course of air-bricks is built under the eaves, and an air-brick, 9 × 9, in walls 6 ft. above floor between every two stalls.

557.

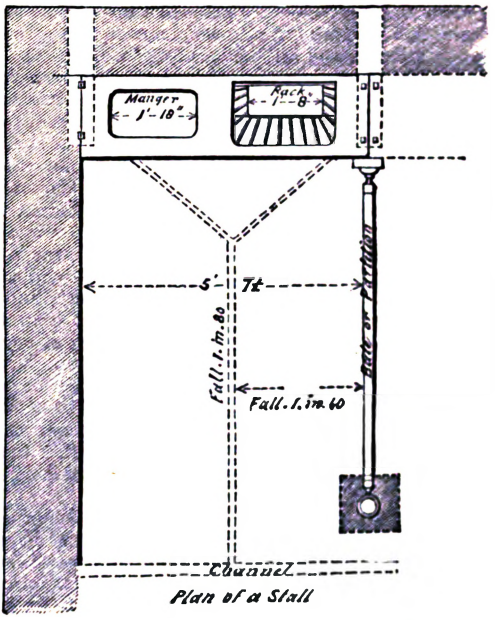



Wrought-iron corn-bins are provided in each hay and straw store; and in the troop stables the saddlery is kept on wrought-iron brackets, screwed into the heel-posts of cast iron. Officers' saddle-rooms are provided with a small stove; and gas and water are generally laid on to all stables where practicable.

559.




558.




Stables should be placed from 30 to 40 ft. in rear of the men's quarters, and large corridors, covered with glass roofs, should be formed between them, so as to afford shelter to the men attending the stables in wet weather. At other times they can be utilized as drill-sheds. The litter-stalls, manure-pits, &c., placed in rear of stables.

The following buildings are generally included in a project for a cavalry barrack:—a riding-school; stores for forage, according to local circumstances; forges; shoeing-sheds; medicine-room; litter-stalls, &c. (and where artillery or military train are quartered, provision must be made for gun and carriage sheds, &c., &c.); workshops for saddlers, harness-makers, &c.

In 1858, when prizes were offered for the best designs for barracks for infantry and cavalry, Mr. H. Wyatt obtained that for the latter, and afterwards prepared plans for a cavalry barrack at Nottingham, which, however, owing to some local difficulties as to site, &c., has not as yet been carried out. The synopsis used by him and all the other competitors was from the Blue-Book containing the Report of the Committee on Barrack Accommodation in the Army, with the Minutes of Evidence, dated 1855.

*Casemated Barracks.*—In nearly all our recently erected fortifications, convenient bomb-proof barracks or casemates for the garrisons are provided, with all the necessary store and other accommodation, and forming a vast improvement on the old casemates at Chatham, Cork Harbour,

Plymouth, and other places, which were so justly reprobated by the Barrack Commission. The new casemated barracks thus constructed will allow the War Department in some degree to make up for the loss of accommodation caused by the enlarged cubical space now allowed to each man, without any particular outlay for this specific object. Properly arranged, a casemated barrack is quite as dry and healthy as one of ordinary construction.

*Temporary Barracks.*—For some time prior to the Crimean war, the formation of large camps, composed not of tents, but of buildings of a more permanent nature, and capable of accommodating not one or two regiments, but a large *corps d'armée* of from 10,000 to 15,000 men of all arms, and necessary war material, had found much favour in the eyes of the military authorities. Commencing with the encampment on Chobham Heath in 1853, the great military camp at Aldershot was next projected in 1854, the site being on a vast expanse of waste land or heath on the borders of Hampshire and Surrey, within a convenient distance of the metropolis (about 35 miles) and our great naval arsenal of Portsmouth, and easily reached by the South-Western Railway, which passes within a short distance of it. Aldershot can now accommodate 20,000 men; and probably up to this date not less than 1½ million sterling has been spent on it.

Another grand training-camp for the troops stationed in Ireland is that of the Curragh, situated on the vast plain of that name in the county of Kildare; it was formed in 1855 for 10,000 men, but is now capable of accommodating many more. There are also large temporary barracks at Colchester; Parkhurst, in the Isle of Wight; Chichester; and Shorncliffe, near Dover. The huts of these camps are principally of framed fir, clap-boarded, and covered with asphalted felt, with a central nucleus of brick fire-places. The framing is raised off the ground by brick sleeper-walls in every case.

The original temporary buildings are being now, especially at Aldershot, gradually replaced by others of a more permanent nature.

The sanitary arrangements, water-supply, roads, &c., of our large camps are generally satisfactory, and the health of the troops better than in barracks situated in large towns.

The principle of construction in our temporary barracks is simply the arrangements of the different units of accommodation for soldiers' and officers' huts round a series of squares; in the Curragh Camp these squares have an area of 380 ft. × 360 ft. for drilling purposes. The soldiers' huts are of a uniform size, 40 ft. × 20 ft., and accommodate 25 men each. The officers' huts are divided into 8 small rooms about 9 ft. square, and the sergeants' something similar; so that space is economized as much as possible. The officers of higher rank are of course better accommodated; but married officers have a just cause of complaint in the very limited space allotted to them, and the wooden buildings in winter afford anything but comfortable lodging to their occupants. The cost of a soldier's hut may be estimated at 85*l.* each.

In Parkhurst Barracks the huts are covered with a rebated tile, which extremely resembles brickwork, and forms a very warm and durable covering.

The arrangement of the old Roman camps, as described by Polybius and Hyginus, might be studied with improvement by modern military engineers.

*Indian Barracks.*—Very extensive improvements have of late years taken place in our Indian barracks, involving indeed nearly a complete reconstruction. A cubical space of 1500 ft. per man is now allowed, and all the buildings are raised some feet from the ground, and surrounded on all sides with a verandah, 10 ft. 6 in. wide. A barrack-room for 24 men—and they seldom hold less—is 100′ × 24′ × 15′. They never exceed two stories in height. Ventilation and drainage are carefully looked after. They are wanting in none of the conveniences and luxuries (if they may be termed so) of our modern home-barracks. A sum of not less than 10 millions sterling has been lately provided by the Indian Government for the purposes of barrack improvement and reconstruction, showing how vastly important this subject is considered in our Indian empire. See 'Suggestions for Improving Barracks at Indian Stations,' issued by the Secretary of State for India, 1864.

*Foreign Barracks.*—On the Continent, barracks are much more numerous than in England. They are generally on a much larger scale and with greater architectural pretensions, although very often deficient both in material comforts and sanitary arrangements: their position, too, is more influenced by political considerations than English barracks are. The men's quarters in Continental cavalry barracks are, like many of our own, often placed over the stables. Generally speaking, the soldiers' quarters are airy enough, though cold and comfortless in winter; and our expensive and well fitted up officers' quarters and mess establishment are altogether wanting.

The great foreign camps at Chalôns, in Rhenish Prussia, Silesia, &c., are on a much more vast scale that any of ours, and have their huts generally formed of *sod* or wattle, thatched with reeds or straw; but these are only occupied during the exercise months in summer and autumn. A French hut to hold 20 men is 6·50 mètres long and 4·35 wide, and 3 30 high to ridge. See Laisnes' 'Aide Mémoire,' p. 598.

In France, sailors as well as soldiers and marines are provided with barracks at all the large naval stations—a system which might be very advantageously adopted by this country, instead of allowing our seamen to disperse over the face of the land when their ships are paid off.

BARRAGE. Fr., *Barrage*; Ger., *Damm Schlagbaum*; Ital., *Chiusa*; Span., *Estacado.*

Barrage is a French term, and signifies, in an engineering sense, the barring of a river or other watercourse by artificial means, in order to facilitate navigation or irrigation in parts where the incline is too rapid, and the quantity of water—from that or other causes—would be insufficient for those purposes were it left to spread freely and in waste over its normal bed.

In mountainous districts and hot countries, but more especially in tropical climes, the rivers are all subject periodically either to a great excess of water or to an almost total want thereof. To-day they are raging torrents, flooding and devastating the neighbouring country; to-morrow, mere streamlets, often fordable, and frequently reduced to the 400th part of their ordinary average volume.

Such irregularities exercise a most detrimental influence over the interests of the populations where they occur. The agricultural prosperity of India, for instance, suffers greatly from these causes; for there, unless aided by artificial irrigation, all cultivation must necessarily cease during the dry season.

In Demerara, Surinam, some parts of Georgia, and a few other places, the evil is in a measure guarded against by the facility which those countries possess of cutting canals and obtaining water from the interior; but, as a rule, it may be said that there is a total absence in all tropical lands of that due provision for regulating the supply of water which is of such vital importance to the welfare and prosperity of every country.

It is not our province to dwell upon the physical causes that determine this state of things; but, having referred in a cursory manner to the very serious damage to commerce and agriculture arising therefrom, we propose to lay before our readers, as concisely as possible, some of the most successful remedies which the engineer's art has from time to time suggested in counteraction of the evil. There is, however, a peculiarity appertaining to the great tropical rivers running through countries having dry seasons, and crossing deltas or alluvial plains, which it may be interesting to mention. It is the fact that the beds of those rivers are sometimes as high as remote parts of the neighbouring country, while their borders are much higher; so that the overflow diverges at nearly right angles to the direct flow. The cause of the bed and sides of these rivers rising above the natural level of the surrounding plains is due to the earthy matter, held in suspension by the natural flow, being deposited in proportion as velocity is diminished.

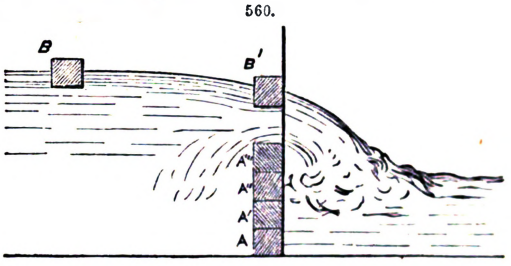
There are two kinds of barrage, the *Barrage* and the *Barrage-mobile*: early examples of the former are found in the permanent dams placed across streams and watercourses, so as to increase or maintain their depth, for the purpose either of rendering them navigable or obtaining a fall with the view of propelling machinery; the surplus water, in such cases, being conducted through sluices, or over by-washes, dams, tumbling-bays, or overfalls, prepared to carry it off; and, in the event of floods arising in the river, additional sluices being opened, in order to prevent it overflowing and injuring the side-dams and adjacent property. Works of this nature may be seen on the Thames, on the Arno at Florence, at the reservoir of Gros-Bois, on the Canal de Bourgogne, on the Vesoult, at Courbeton, at Conflans-sur-Seine, and on numerous other canalized European rivers; and although they will hardly bear comparison, in point of magnitude, with those executed in tropical regions, nevertheless many of them are of sufficient importance to deserve special mention in the course of this article.

BARRAGE-FIXE is the term applied to permanent dams, built of masonry.

BARRAGE-MOBILE, or *movable barrage*, is that which can be raised, lowered, or removed at will, and is formed partly of masonry, partly of timber.

The most simple form of *barrage-mobile* is that represented in Fig. 560, where the current of water passes between two lateral walls, whose intervening space is partially closed by a certain number of small beams A, A′, A″, A‴, superposed, and forming an overfall by which the liquid flows into the trough below. The advantage of this plan is, that it enables the ridge of the weir to be heightened or lowered at pleasure, and with very great facility.

560.




A rather remarkable phenomenon is connected with this sort of barrage. When it is required to raise it, another beam B, floating in the upper trough, is borne by the stream till it reaches B′, where its extremities rest against the rabbets that secure those already fixed; but no sooner has it attained this point than it is seen suddenly to sink, falling straight on to the beam A‴, and thus taking up its allotted position as if by instinct.

This fact is easily explained. The space that separates the beams A‴ and B′ forming a kind of adjutage, the pressure upon the under surface of B′ becomes less than the atmospheric pressure exerted upon its upper surface (see HYDRAULICS). The beam acts, therefore, in obedience to the difference of those two forces augmented by its own weight.

It must be observed that the first beams A, A′, which have to be put beneath the level of the lower trough, do not sink thus naturally into position: in order that the phenomenon may take place, they must already be in sufficient number to rise above the surface of the water in the nether basin, so as to produce a fall.

A difficulty arises in ascertaining the exact coefficient of the expenditure of fluid, by a dam or overfall, which it is important to point out before proceeding further.

An *Overfall* is an orifice, open at the top, and the lower part of which presents a flat, horizontal surface called a *Sill*. The lateral edges being generally vertical, the opening may be considered as a rectangle, of which the upper side has been removed; this assimilation would still be admissible even in a case where the length of the sill, in relation to the thickness or depth of the sheet of water passing over it, was very great.

Let L be the length of sill;

$y$ the vertical distance between the sill and the surface of the liquid at some point of the reservoir where it would be comparatively stagnant;

$\eta$ the thickness of the sheet of water passing the overfall;

Q the expenditure in a second of time.

The water being supposed to flow freely into the open air, we find that for one molecule, starting from the reservoir without any sensible initial velocity, and actually traversing the vertical plane of the sill, the load varies from $y$ to $y - \eta$, which shows at once that $\eta$ must be

smaller than $y$; for, by virtue of Bernoulli's theorem (see HYDRAULICS), no flow can take place where the load is negative. The velocity corresponding to the mean load will therefore be

$$\sqrt{2g\left(y-\frac{1}{2}\eta\right)},$$

and, as the section of the orifice is represented by $L\eta$, the theoretical expenditure will be expressed by $L\eta\sqrt{2g\left(y-\frac{1}{2}\eta\right)}$. If, then, we designate by $m$ the coefficient of expenditure as applied to the flow in the present instance, we shall have $Q = mL\eta\sqrt{2g\left(y-\frac{1}{2}\eta\right)}$.

In the foregoing expression $\eta$ and $m$ are unknown auxiliaries that no theory has been able yet to determine. The only thing we know is that $\eta$ must be smaller than $y$, and experience shows that the ratio $\frac{\eta}{y}$ is inconstant, but that it rarely descends below 0·72 for overfalls having a narrow sill: we will suppose, therefore, its mean value to be equal to 0·86. As regards $m$, since it varies very little with the load or the dimensions of a narrow-edged orifice, we may reasonably assume it to be equal to the mean 0·62. We thus obtain

$$Q = 0{\cdot}62 \times 0{\cdot}68\, Ly\sqrt{2g \times 0{\cdot}57y}$$
$$= 0{\cdot}403\, Ly\sqrt{2gy}.$$

In reality, if we put $Q = rLy\sqrt{2gy}$, $r$ being a ratio that can only be determined experimentally, it is evident that it has not a constant value. MM. Poncelet and Lesbros, in experimentalizing upon a narrow-edged overfall, $0^m{\cdot}20$ in length, and sufficiently distant from the bottom and lateral sides of the reservoir, found that $r$ varied from 0·385 to 0·424; its greatest value corresponding to the smallest loads. The mean of these two numbers is 0·405, which differs but little from the result 0·403 obtained above. So that for narrow-edged overfalls, placed at a sufficient distance from the bottom and sides of the reservoir, and flowing freely into the open air, we find $Q = 0{\cdot}405\, Ly\sqrt{2gy}$ nearly: but this formula may give a result either a little too great or a little too small, according as the ratio $\frac{y}{L}$ is great or small.

It is very difficult, even by approximate valuations, to keep an account of all the circumstances and local conditions that may tend to influence the value of $r$. We may observe, however, that if a canal be barred across its entire width by a narrow-edged overfall whose sill is tolerably distant from the bottom, and if, at the same time, $\frac{y}{L}$ be small, it would be advisable to make $r$ a little larger, and to put $Q = 0{\cdot}45\, Ly\sqrt{2gy}$, or, which is the same thing, $Q = 2\, Ly^{\frac{3}{2}}$.

We will now cite a particular and rather remarkable case, inasmuch as it shows how theory may give an increased limit to the coefficient $r$ and the corresponding value of $\eta$. It is that where the sill B of the overfall, Fig. 561, widening at its junction with the reservoir, is prolonged by means of an open channel, slightly inclined, wherein the liquid acquires a sensibly uniform motion. Then the common velocity of all the streams passing A B is $\sqrt{2g(y-\eta)}$; and, as there is no further contraction beyond the above section, the expenditure Q is given by the formula $Q = L\eta\sqrt{2g(y-\eta)}$.

561.

When L and $y$ are invariable, Q becomes a function of $\eta$ only, and its maximum is easily found. For, in fact, $\frac{Q^2}{2gL^2} = \eta^2(y-\eta) = y\eta^2 - \eta^3$: the maximum of the second member, and consequently that of Q, is found by making the derivation taken in relation to $\eta$ equal to zero, which gives $\eta(2y - 3\eta) = 0$, whence $\eta = \frac{2}{3}y$, since $\eta = 0$ would lead to an expenditure that would be nul. Then, in the expression of Q, by making $\eta = \frac{2}{3}y$, we get

$$Q = \frac{2}{3\sqrt{3}}Ly\sqrt{2gy} = 0{\cdot}385\, Ly\sqrt{2gy}.$$

The surface depression $y - \eta$ corresponding to the maximum expenditure is, therefore, one-third of the height $y$, and the value of the corresponding ratio $r$ is 0·385. As the theoretical hypotheses are never completely realized in practice, if the sill of the overfall be followed by a channel, $r$ will very rarely attain the superior limit 0·385. According to MM. Castel and Lesbros, the mean expression for an overfall like the present would be $Q = 0{\cdot}35\, Ly\sqrt{2gy}$; but here again there may be a very great variation in the ratio $r$ between one overfall and another.

When, in lieu of there being a comparatively stagnant reservoir above the overfall, there is a current with an appreciable velocity $U_0$, the expressions $\sqrt{2g\left(y-\frac{1}{2}\eta\right)}$ and $\sqrt{2g(y-\eta)}$,

considered above, no longer represent the velocity of the streams of liquid passing over the sill. If we call that velocity U, Bernoulli's theorem then gives $\frac{U^2 - U_0^2}{2g} = y - \frac{1}{2}\eta$, or $\frac{U^2 - U_0^2}{2g} = y - \eta$, according as the question has reference to an orifice discharging freely into the air, or to one followed by an open channel.

Although, in a general sense, it is possible to tell, with a sufficient degree of exactitude, the velocity with which a liquid flows from a narrow-edged orifice—whether that orifice be plane, or widening towards the interior of the reservoir, or followed by an open channel slightly inclined—there yet remains one quantity of far greater practical importance, which, unfortunately, it is not so easy to ascertain, and that is the expenditure. This last depends not only upon the velocity with which the molecules pass the plane of the orifice, but also upon the angles at which the several liquid streamlets intersect that plane, angles that vary from one point of the orifice to another according to laws at present unknown. The only positive assertion that can be made is, that the real expenditure of water is *less* than the product of the area of the orifice by the velocity of the streams traversing it, which quantity has been improperly termed the *theoretical expenditure*. We have indicated several numbers which, in certain special cases, will afford an approximate solution of the question. In reality, however, in each of those particular cases the coefficient of expenditure is inconstant, and varies according to secondary circumstances, whose influence is very imperfectly known, such as the dimensions of the orifice, and its position in relation to the bottom and sides of the reservoir. Consequently, the only advice we can give, when the approximation obtainable by the mean coefficients of expenditure which we have indicated is not deemed sufficiently satisfactory, is to select from known collections of experiments those that bear the closest relationship to the case under investigation, and to borrow therefrom the coefficient that appears to be the best applicable.

The Tables at the end of this article, and which are taken from the more complete and extended ones published by MM. Lesbros and Poncelet, give the coefficients of expenditure which we consider the most useful in practice.

The abrupt sectional changes that take place in watercourses give rise to various problems that are of great interest to the engineer. Unfortunately, the actual state of science renders it impossible at present to solve them in so satisfactory a manner as would be desirable. In the following example, theory supplies us with a few data—incomplete and inaccurate, no doubt,—but capable, nevertheless, of being utilized in practice.

Under ordinary circumstances, the sill of the barrage is higher than the level of the water in the lower trough; but, where the current is variable, it sometimes happens that the latter rises above the weir, as shown in Fig. 562; the barrage is then said to be *noyé*, or *submerged*.

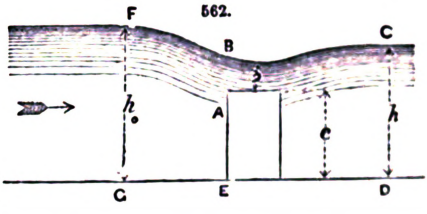
Let us suppose a barrage, or overfall, to be thrown across a watercourse, of which the level—and consequently the expenditure—are variable: in order to simplify as much as possible the calculations that have to be made, we will imagine the channel in the vicinity of the barrage to be rectangular and the bottom horizontal. The expenditure having a definite and known value, it is required to find: 1, the greatest height to which the lower level of the water can rise without in any way affecting the upper level; 2, in the case of that limit being exceeded, what would be the nature of the fall that would ensue from the upper to the lower trough.

Let L be the width of the current; $h$, its depth above and a few mètres from the weir; $U_0$ its mean velocity at that point; $h$ and U analogous quantities for a section taken a little below the fall; $c$ the height between the crest of the weir and the bottom; $v$ the velocity of the sheet of liquid passing over the crest; $\eta$ the thickness of that same sheet of liquid.

There being no lateral contraction, if the barrage acts as a narrow-edged overfall, the expenditure Q will be given by the formula $Q = 0{\cdot}45\ L\left(h_0 - c + \frac{U_0^2}{2g}\right)\sqrt{2g\left(h_0 - c + \frac{U_0^2}{2g}\right)}$.

If the crest, instead of being narrow-edged, happened to be of some considerable length, with a slight incline, then the coefficient 0·45 ought to undergo a certain reduction, and descend to 0 385, or even to a lower number, such as 0·36 or 0·37. The formula holds good so long as the overfall empties itself freely into the open air, to accomplish which it is necessary only that the level of the water in the lower trough be beneath the crest of the weir. When it exceeds that point, but only by a quantity less than $\eta$, it appears evident that the formula must not be modified: the very utmost that can happen is that the streamlets, losing their parabolic form, and becoming parallel as they cross the overfall as in the case when this latter is of any great thickness or width, the numerical coefficient would have to be reduced, as just stated: which would tend slightly to raise the level above the weir, the expenditure remaining the same. In examining the question more closely, it is seen that the level below the weir may be raised even higher yet without any perceptible alteration taking place in the expenditure.

562.




Effectually, if we apply the general theorem of the quantities of motion projected, to the liquid contained between the vertical plane A B, Fig 562, which passes through the sill of the barrage, and the section C D where the velocity is U, it will at once be found that the algebraical increment of the quantity of motion of the system projected along the horizontal line during a very short space of time, $\theta$, is $\frac{\Pi Q \theta}{g}(U - v)$, admitting that all the molecules of the same section possess the same velocity. As to the impulses, we need only keep account of those produced by the

pressure on the surfaces B A E and C D, disregarding the atmospheric pressure which acts uniformly upon the entire system. These pressures must accord very nearly with the hydrostatic law, in the first place because the streams are ostensibly parallel as they traverse A B and C D, and because the motion of the liquid in contact with A E is comparatively slow; hence the value of the projected impulse is $\frac{1}{2}\,\Pi\,\theta\,L\left\{(c+\eta)^2-h^2\right\}$. We have, therefore,

$$\frac{\Pi\,Q\,\theta}{g}(U-v)=\frac{1}{2}\,\Pi\,\theta\,L\left\{(c-\eta)^2-h^2\right\};$$

or, by simplifying, $\frac{2\,Q}{L\,g}(U-v)=(c+\eta)^2-h^2$. We moreover have $\frac{Q}{L}=v\,\eta=U\,h$; and, by eliminating Q and U, the former expression becomes $\frac{2\,v^2}{g}\,\eta\left(\frac{\eta}{h}-1\right)=(c+\eta)^2-h^2$, equation of the third degree in $h$, whence that quantity might be deduced if $v$ and $\eta$ were known. In order to find those unknown auxiliaries, it must be admitted, in conformity with what has been seen in the theory of the overfall, that the surface depression $h_0-\eta-c$, above the fall, is connected with the total load upon the sill by the equation $3\left(h_0-\eta-c+\frac{U_0^2}{2g}\right)=h_0-c+\frac{U_0^2}{2g}$, whence we derive $3\,\eta=2\left(h_0-c+\frac{U_0^2}{2g}\right)$, which, in combination with

$$Q=0{\cdot}37\,L\left(h_0-c+\frac{U_0^2}{2g}\right)\sqrt{2g\left(h_0-c+\frac{U_0^2}{2g}\right)},$$

in order to find $\eta$, would give $Q=0{\cdot}37\,L\times\frac{3}{2}\,\eta\,\sqrt{2g\times\frac{3}{2}\,\eta}=0{\cdot}68\,L\,\eta\,\sqrt{2g\,\eta}$.

Having found $\eta$, we calculate $v=\frac{Q}{L\,\eta}$, and we thus obtain the necessary elements to arrive at the numerical value of $h$. If, on the other hand, the depth of water below the fall were to exceed the aforesaid limit, what would be the depth above the weir?

In order to answer this question—supposing the expenditure Q to remain constantly the same—let us indicate the alteration that takes place in $\eta$, $v$, $h_0$, $U_0$, $h$, by $\eta'$, $v'$, $h'_0$, $U'_0$, $h'$: we then get the following equations:—

$$\frac{2\,\eta'\,v'^2}{g}\left(\frac{\eta'}{h'}-1\right)=(c+\eta')^2-h'^2,\quad \frac{v'^2}{2g}-\frac{U'^2_0}{2g}=h'_0-c-\eta',\quad \frac{Q}{L}=\eta',\ v'=h'_0U'_0,$$

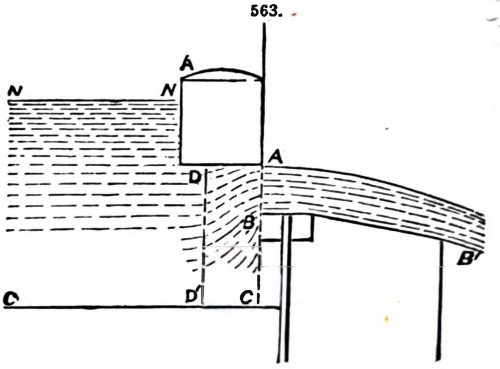
whereof the first and two last are known; the second is an immediate application of Bernoulli's theorem to the passage of a molecule from the section F G, where the velocity is $U'_0$, to the section A B. By means of these four equations the unknown quantities $\eta'$, $v'$, $h'_0$, $U'_0$, may be determined, when Q and $h'$ are given. The thickness $\eta'$ of the sheet of water A B cannot be calculated by the same expression as $\eta$, because the barrage acts no longer as an overfall.

The influence of a barrage, when submerged, becomes less and less perceptible; that is to say, the fall $h'_0-h'$ grows smaller and smaller as the level of the water below the weir rises. This will be understood *a priori*, without any mathematical demonstration; for, if the barrage be covered by a sheet of water much higher than itself, it will then occupy but a small fractional portion of the transverse section, and thus, in a measure, may be compared to a slight undulation of the bottom.

*Bateau-vanne*, or *floating-gate*, is the name given to a sort of self-acting, movable barrage, invented by M. Sartoris, and which, in point of simplicity, comes next under our notice. It is used chiefly for purposes of irrigation, and for regulating the supply of water in mill-ponds, and is as follows:—

A caisson, or *boat* as the French term expresses it, A A, whose transverse section is rectangular, rests against two stone piers, the space separating these being partially closed by a platform B B', Fig. 563, raised above the bottom C C of the river. The water passing between A and B has a certain velocity U, while the streams that pass beneath the boat have a less velocity U'. If we call $h$ the height of A below the level N, we have $\frac{U^2}{2g}=h$. On the other hand, if, within a given section D D', all the streams could be reckoned as parallel and having an equal velocity, and $a$ and $b$ were taken to designate the heights A B and D D'—the opening being supposed to be rectangular—the incompressibility of water would give $U\,a=U'\,b$, which relationship is necessary in order that the mass of water comprised between A B D D' may remain always the same. Finally, by applying Bernoulli's theorem to a molecule passing from the point D, with a pressure $p'$ and a velocity U', to the point A where those quantities become $p$ and U, we have the equation

563.




$$\frac{p'-p}{\Pi}=\frac{U^2-U'^2}{2g}.$$

From these three relations it is not difficult to deduce

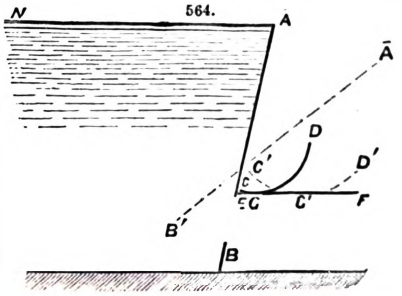
$$\frac{p' - p}{\Pi} = h\left(1 - \frac{a^2}{b^2}\right).$$

This calculation of the pressure $p'$ upon the bottom of the float may be a little uncertain, especially as the velocities of the molecules that traverse the section D D' are not all equal, and the converging of the streams towards the orifice A B prevents them also being horizontal; but it is quite sufficient to show that $p'$ must be greater than $p$, and that the excess increases with $h$. The weight of the boat and its friction against the piers may sometimes be inadequate to establish equilibrium with the vertical force produced by the excess $p' - p$; in that case this is what is done: on the side facing the upper trough are several cocks, by means of which water enough is let into the caisson to balance it in the position it is intended it shall occupy. If it be required to sink it lower, more water is let in; if, on the contrary, it has to be raised, another set of cocks, facing the lower trough, are opened, the water flows from them, and the boat rises as it becomes lighter.

The two following styles of flood-gate are by M. Chaubart. They have been tested on the canal that borders the Garonne, with very satisfactory results, and for which the inventor received great praise. It would seem, therefore, that they may be serviceably employed for purposes of navigation and irrigation, as well as in regulating the level of mill-ponds. We have thought proper to introduce them here because they bear a rather close relationship, in principle, to a system of barrage-mobile now getting into very general use in France, and of which we shall presently have to speak at some length.

*First Plan.*—A canal, whose section is rectangular, is closed by an inclined gate A B, Fig. 564, occupying its entire width. To this gate is permanently fixed a quadrant C D, made of cast iron, which rolls on the horizontal plane E F. When the gate is in its initial position, the level N of the water touches its summit, and it must be so arranged that the resultant of the forces of gravity and the pressure of the water, acting upon the apparatus, shall pass through G, the actual point of contact of C D and E F. Equilibrium is then established. But if, from any unforeseen cause, it so happens that more water comes into the trough above, and that the level N rises, the centre of pressure rises with it, and the resultant advances in front of G. The gate then swings *en bascule*, till it assumes the position A' B', and the point of contact of the curve is removed from G to G', while the surplus water runs off both at A' and B'.

564.

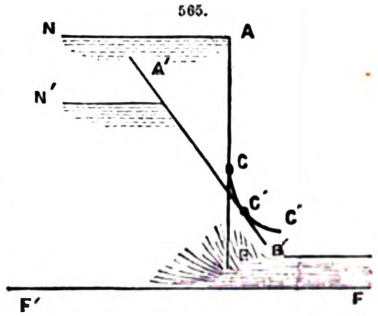



It may so happen, when in this new position A' B'—if the curve C D has been properly determined—that the resultant will pass through G after the level has returned to N. In that case it is clear that the gate will remain in the position A' B', and that it will only quit it when a further rise causes its angle of inclination to be increased, or when an additional fall in the level forces it to right itself. In a word, whatsoever position it may assume, it will only remain in equilibrium so long as the level of the water in the tank reaches its normal height:—a greater height will widen the outlet, a less height will contract or close it. The apparatus may consequently be used to ensure a constant level of water in a reservoir where the supply is variable.

*Second Plan.*—By the aid of the gate just described, M. Chaubart has solved, as we have seen, the problem of obtaining a constant level in a reservoir where the *supply* is variable. Now, on the contrary, it is wished to get a constant and equal supply of water through a rectangular opening in a tank where the *level* varies. We will explain in what manner M. Chaubart has effected this object.

When in its natural position, the gate A B, Fig. 565, leaves a free outlet for the water between its lower edge and the bottom of the basin. The level N of the water, being now supposed to have attained its maximum height, nearly touches the top A of the gate, while a certain given quantity Q of water is discharged, in the unity of time, by the above rectangular opening whose dimensions are known. The gate is kept in equilibrium by the line A B resting against a fixed curve C C' C'', and the resultant of the actions exercised by the pressure of the water and by gravity passes through the point of actual contact C. When the level falls to N', the total pressure necessarily diminishes in proportion, and the gate swings *en bascule* till it finds another position of equilibrium A' B', which line rests upon a different point, C', of the fixed curve; while the point B, advancing to B', the section of the outlet, on the other hand, is proportionately increased. It may easily be conceived, then, that if the curve C C' C'' has been properly traced, it is quite possible for the enlargement of the orifice to compensate for the diminution of pressure. If, now, we call $l$ the width of the outlet, $y$ the height of B' above the bottom F F', Y the height of the level N' above the same horizontal line, $m$ the coefficient of expenditure applicable in the present instance, the invariability of the expenditure will be expressed as follows:

565.




$$Q = m l y \sqrt{2g\left(Y - \frac{1}{2}y\right)}.$$

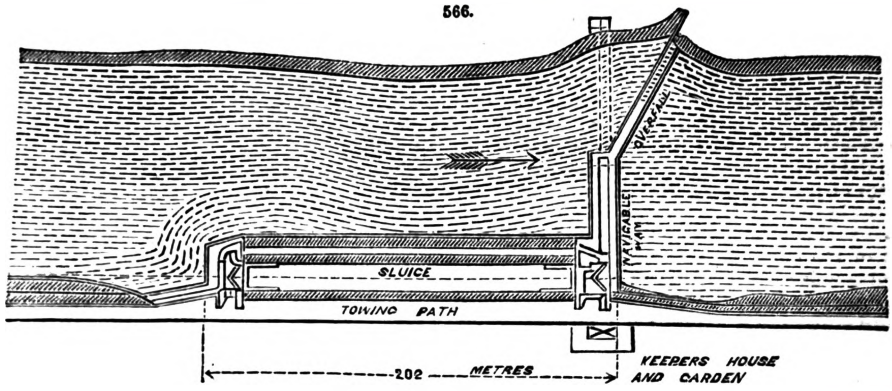
from which equation may be deduced the values of Y in relation to $y$, and inversely.

Unfortunately, it is very difficult to ascertain the exact shape of the required curve; therefore, as the limits and nature of this work will not allow us to enter into a long theoretical investigation, we will content ourselves with laying before our readers an approximate graphical method.

It must be admitted that during the displacement of the gate the straight line A B turns upon a certain curve, which has to be determined in such a manner as to fulfil the essential conditions of the problem. In the first place, the initial point C of the curve, Fig. 565, will be known by taking the intersection of A B with the resultant R of the weight of the gate and the pressure of the water. Let us next imagine the line A B to undergo a slight change of position in the direction of A′ B′; during this movement it will have turned round an instantaneous and variable centre of rotation between C and C′, and, consequently, the approximate supposition will be admissible, that its entire rotation took place round the point D, where the tangents D C and D C′ to the curve C C′ meet. But, as that point is not known, it must be taken, by guess, a little below C′, and the line A B is made to move at a slight angle round the centre D; in this fresh position, the extremity B, now arrived at B′, being at a certain height $y$ above the bottom F F′, Y has to be calculated by aid of the last equation; we then draw the new resultant R′ of the weight and pressure, and find its intersection C′ with the last position of A B. We shall ascertain that the point D, around which A D has been made to turn, was properly chosen if it happens to be equidistant from C and C′; if that be not the case, we shift the point D primitively adopted, and a second attempt will give, in a sufficiently approximate manner, both the line A′ B′ and the second point C′ of the curve sought. From that one we pass to another, and so on, till the required curve is ultimately traced by a series of points or tangents.

*Components of a Movable Barrage.*—A movable barrage, established across a navigable river, comprises two essential parts, namely, the navigable way and the overfall, see Fig. 566.

566.




The former is used for purposes of navigation when there is a sufficient natural draught of water in the river for ships to pass; the movable lifts which serve to close the way are then laid flat on their platform.

The overfall serves to maintain the level of the river at a determinate height when the barrage is in use; it likewise serves as an outlet for the water while the lifts of the navigable way are being raised.

In addition to these two essential parts, there is generally, also, a lock through which the navigation takes place when the barrage is closed, see Fig. 566; when there is no lock adjoining, then the navigation can only be performed by removing the barrage and releasing the water at certain fixed periods.

The *sill* or *platform* of a navigable way should be placed at a depth not less than that of the bottom of the river above the weir.

On the Upper Seine these sills are $0^{m} \cdot 60$ below low-water mark.

The sill of the overfall should be so raised that—having due regard to economy and facility of construction—its section, added to that of the navigable way, shall offer an outlet proportional to the quantity of water that flows down the river at its different periods. Moreover, it must be at such a height that it may give free passage to the waters of the river while the lifts are being raised without producing too heavy a fall from the upper to the lower basin; these conditions are most important.

There necessarily exists, therefore, a relation between the section of the navigable way and that of the overfall; and another, moreover, between the width of the latter and the height of its sill.

The sills of the overfalls on the Upper Seine have been placed at $0^{m} \cdot 50$ above low-water mark.

The establishment of a navigable way is a costly work; its breadth should, consequently, not be greater than is absolutely necessary for the requirements of navigation.

On the Yonne the breadth of the navigable ways is 35 mètres; on the Upper Seine, between Montereau and Paris, it varies from 40 to 55 mètres, measured perpendicularly to the course of the river.

The width of the overfalls ranges between 60 and 70 mètres.

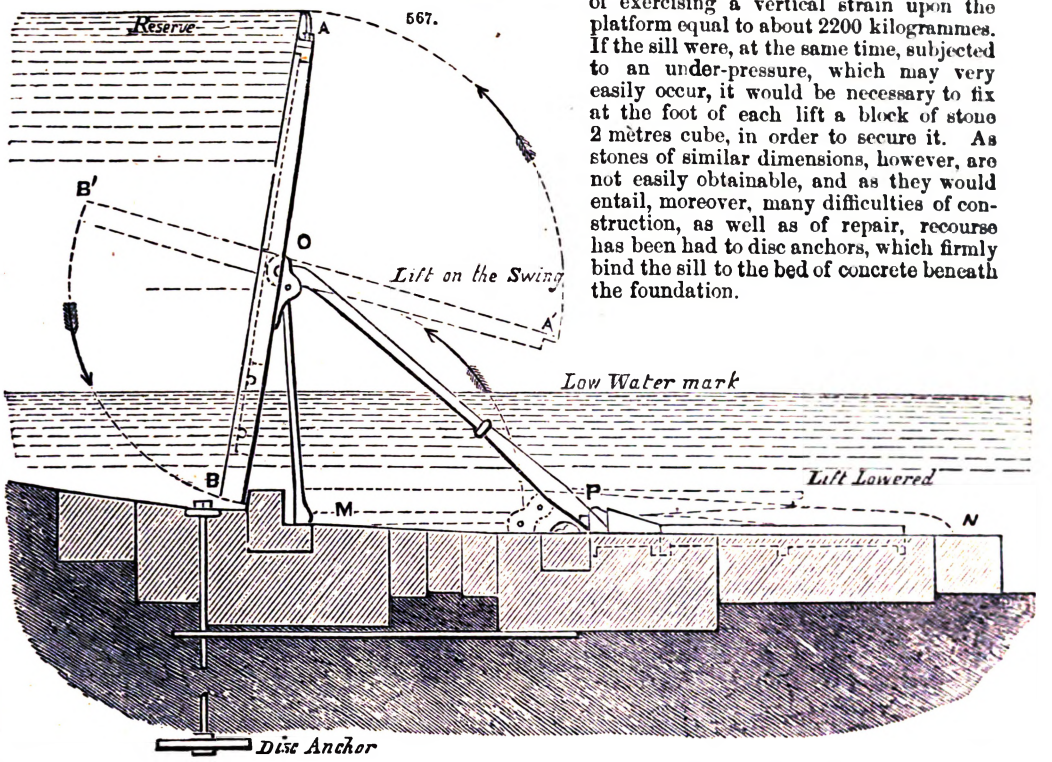
When the breadth of the river will not admit of the overfall being placed perpendicularly to its course, and in a line with the navigable way, it may be put obliquely, as shown in Fig. 566; in that case the angle of inclination must not be less than 60 degrees.

The platform of the navigable way should be of sufficient width to receive all the various components of the lifts, dams, &c., when the foundations are laid upon concrete.

On the Upper Seine, that width is $9^{m} \cdot 50$, divided into three zones, namely: two measuring $1^{m} \cdot 75$ for the piers, and the third 6 mètres for the pavement destined to receive those portions called the movable parts of the barrage. The platform, moreover, must be of such a thickness as will enable it to resist the different pressures and forces to which it has to be subjected.

On the Upper Seine that thickness is 2 mètres, irrespectively of the pavement.

When the difference of level between the upper and lower basin is as much as $2^{m} \cdot 40$, as is the case at the several barrages of the Upper Seine, each movable lift of the navigable way is capable of exercising a vertical strain upon the platform equal to about 2200 kilogrammes. If the sill were, at the same time, subjected to an under-pressure, which may very easily occur, it would be necessary to fix at the foot of each lift a block of stone 2 mètres cube, in order to secure it. As stones of similar dimensions, however, are not easily obtainable, and as they would entail, moreover, many difficulties of construction, as well as of repair, recourse has been had to disc anchors, which firmly bind the sill to the bed of concrete beneath the foundation.




A glance at the above cut, Fig. 567, will make this arrangement clearly intelligible. There is a separate anchor for every lift, and they are fixed in position before the concrete is poured in, their rods or shanks being kept vertical during the operation.

In the navigable ways of the Seine, the pressure in the direction of the buttress of each lift is equal to about 4500 kilogrammes, producing a horizontal component equal to about 3500 kilogrammes. This component tends to make the piles of the foundations give way, and cause the mass of concrete to pivot towards the lower basin. When, however, the piles are well driven in and bound together, no such disturbance need be feared; but, as the layers of concrete below the fall may possibly be undermined by the water, it is requisite that the pavement of the platform be able to resist, by its power of adhesion alone, a sliding force equal to 3500 kilogrammes for every lift. If, then, we take 1100 kilogrammes only as representing the adhesive force of each square mètre of masonry, we find that the adhesion added to the friction gives a power of resistance greatly exceeding 3500 kilogrammes, so that little danger need be apprehended.

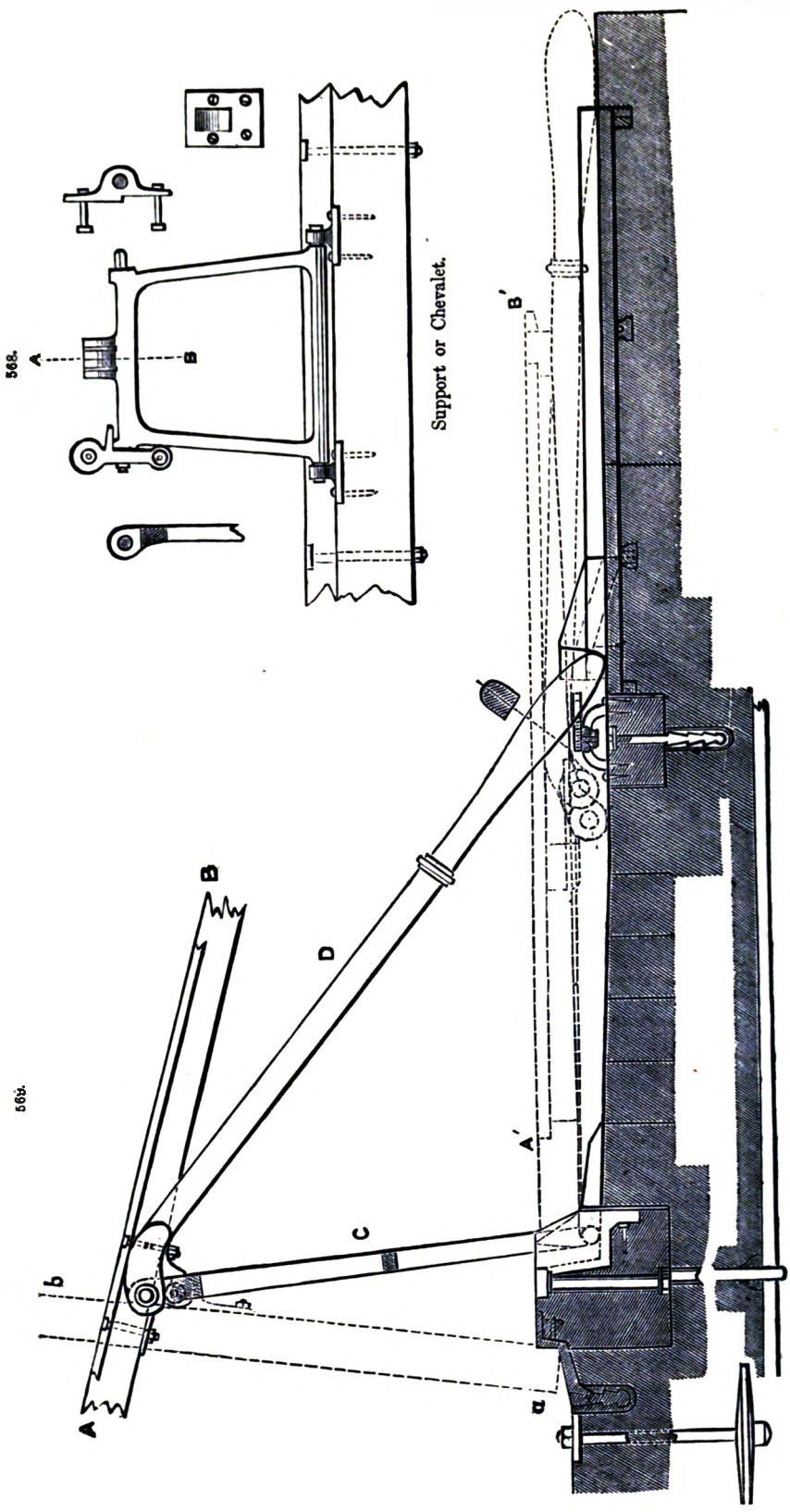
The lift of a navigable way is composed of three principal parts, namely:

1st. Of a framework of timber susceptible of moving upon a horizontal axis placed perpendicularly to the direction of the current. When this framework is raised, it is supported by its axis, while its base rests against a sill attached to the platform of the barrage.

2nd. Of a *chevalet* or stay, made of iron, and bearing the horizontal axis mentioned above. The lower part of the chevalet is terminated by two spindles working in sockets that are attached to the sill against which the foot of the lift rests, Fig. 568; so that this chevalet is able to turn upon its base, carrying with it, as it moves, the framework of the lift.

3rd. Of a buttress of iron, the head of which forms an articulation with that of the chevalet, its foot resting against a cast-iron shoe, firmly cemented in the platform

These three pieces are all that constitute the lift, and the whole arrangement presents very much the appearance of a painter's easel with a picture upon it, as will be seen by the foregoing illustration. Fig. 567, already referred to, shows the lift raised; A B being the framework of timber, O the centre on which it oscillates, A' B' its position when giving way to the water, and M N its position when lying flat on the platform to allow the passage of vessels. But, in order to make the arrangement better understood, we give an enlarged cut representing the chief features of the system, Fig. 569, wherein A B shows the framework or wooden swing-gate, *a b* its position when raised, and A' B' its position when lowered, C the chevalet, and D the buttress or prop.


562.
A
B
Support or Chevalet.
563.
B
D
B'
A'
C
b
A
a

This is the system that has been so successfully and ingeniously put into practice by M. Chanoine at the celebrated barrage of Conflans-sur-Seine—of which a general view is here shown, Fig. 570—and at various other places.

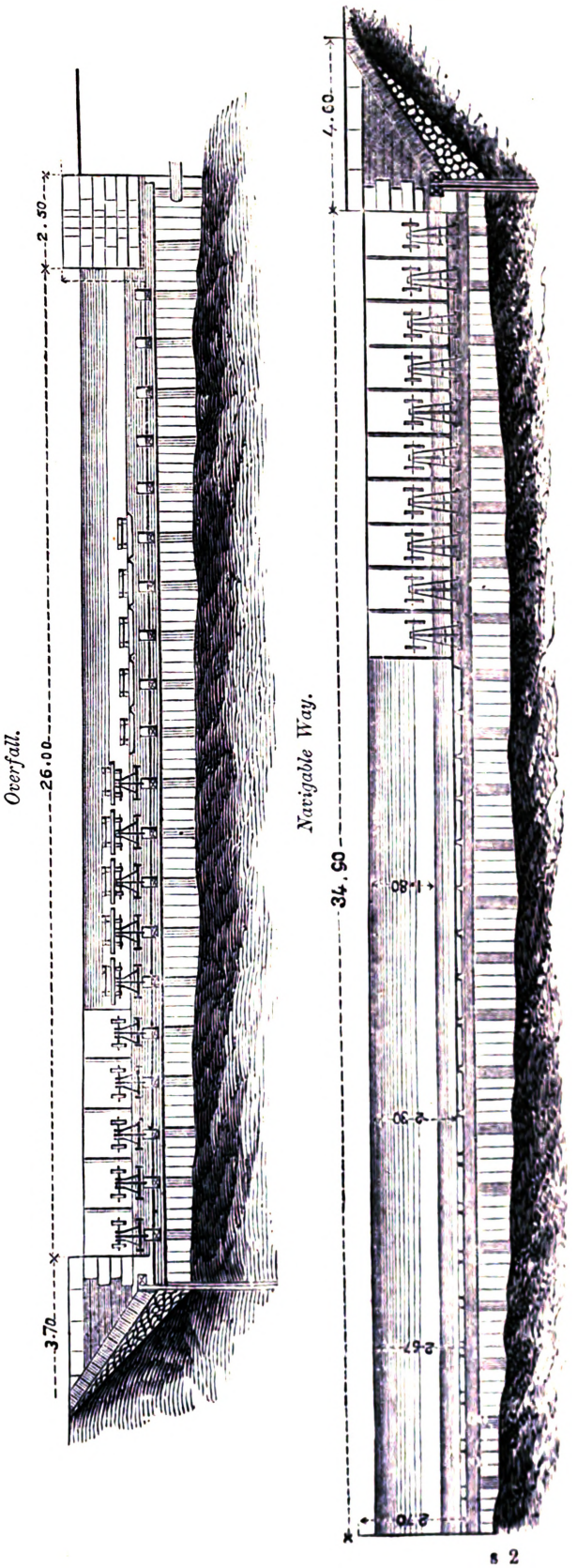
Besides the three principal components of a lift, above described, there remains yet one addition of some import:

The *Counterpoise*.—Upon referring to the several illustrations, it will be observed that that portion of the lift which is above its axis of suspension, and which is called the *volée*, or *fly*, is wedge-shaped, getting thinner towards the top; whereas that which is below the axis of suspension is uniform in its thickness, which is equal to the thickest part of the fly. This is done in order to nearly balance the gate, giving the lower portion, however, a slight preponderance over the upper, which has a longer radius. The moment of the weight of the timbers forming the lower part, called the *culasse*, or *breech*, is about 110 out of water; and that of the timbers of the fly is nearly equal to it: but when the breech is entirely immersed, the moment of its weight is destroyed by the very fact of immersion; so that, in manœuvring, the weight of the fly becomes an obstacle to the lowering of the breech: to remedy this it was necessary to append a counterpoise to the latter, Figs. 571 and 572, composed of a mass of cast iron, movable, and held and guided by three parallel iron bars, Fig. 572, along which it may slide, and weighing about 66 kilogrammes. The moment of this counterpoise, together with the rest of the ironwork of the breech, is about 96.

In order to give some idea how the system operates, let us suppose a lift to be raised and in position, and then observe by what means it is lowered.

If the end of the buttress, which is rounded, be drawn on one side from the shoe, it is evident that, losing its point of support, it will slide upon the platform in the direction of the pressure exerted against the lift; that the *chevalet* will necessarily follow the buttress, turning upon its base; and that the gate itself, in rotation, will follow the *chevalet:* so that the two former will be stretched upon the platform in prolongation of one another, while the latter rests on the top of both, covering them. See Fig. 569.

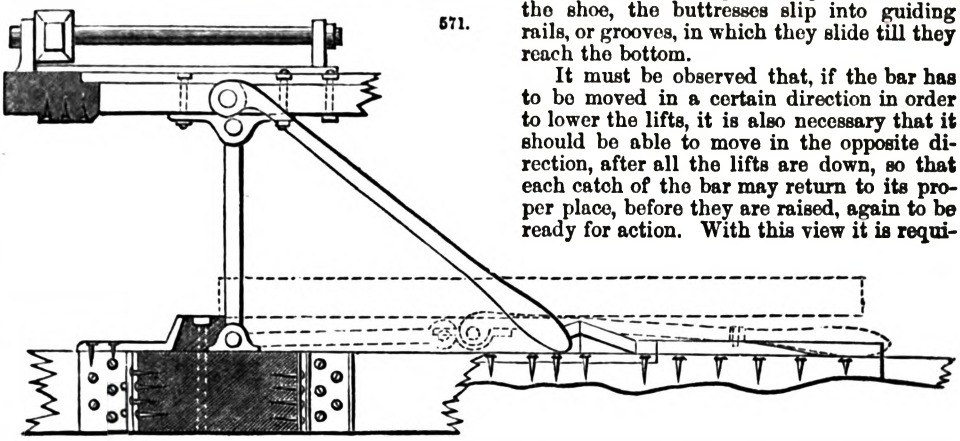
The buttresses are made to slip from their respective shoes by means of an iron bar, placed horizontally upon the platform, and furnished with catches, so disposed at distances that they draw aside the buttresses one by one, in succession, and in the order in which it is intended to lower the lifts. This bar must be easy of management, and arranged in such a manner




570.

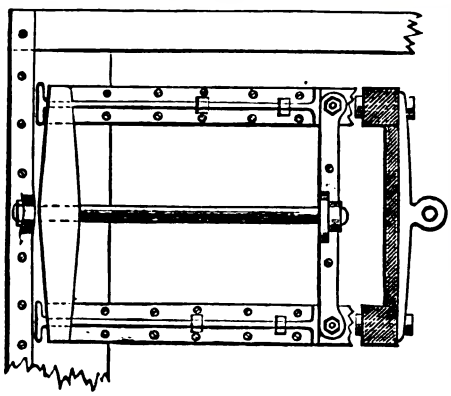
that its action may not be impeded by gravel, sand, or any foreign matter carried down by the current. It is terminated at one end by a rack worked by a vertical wheel, by the aid of which its motion is imparted and thence transmitted from buttress to buttress. Upon being released from the shoe, the buttresses slip into guiding rails, or grooves, in which they slide till they reach the bottom.

571.



It must be observed that, if the bar has to be moved in a certain direction in order to lower the lifts, it is also necessary that it should be able to move in the opposite direction, after all the lifts are down, so that each catch of the bar may return to its proper place, before they are raised, again to be ready for action. With this view it is requisite so to arrange that there may be a chamber reserved beneath the articulation of the chevalet and buttress wherein the bar may freely work.

572.

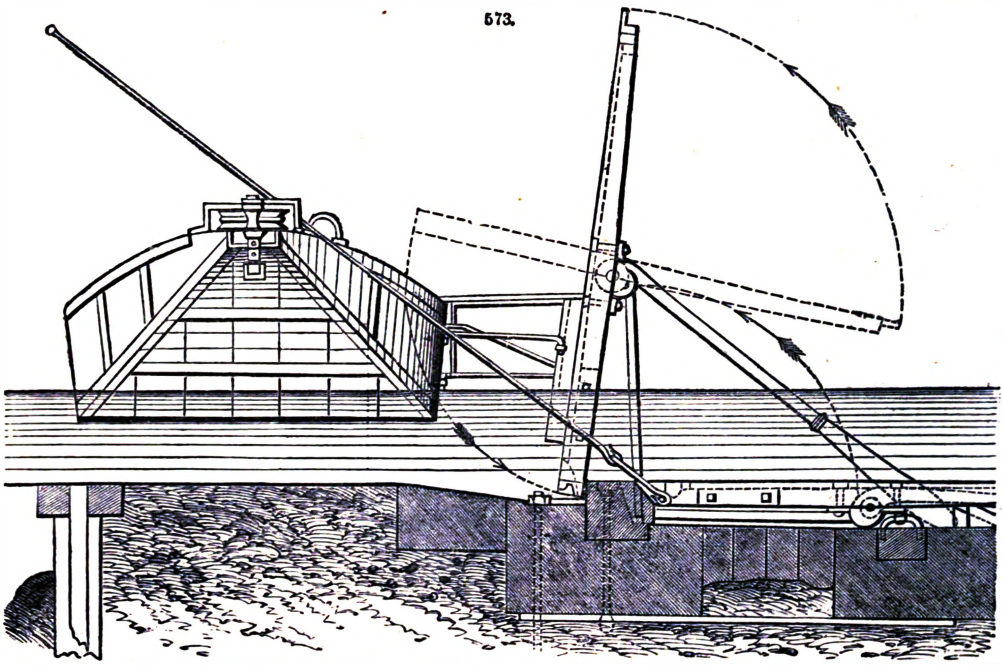


We have already implied that the lift proper is divided by its axis of rotation into two distinct parts: the lower part it has been agreed to call the *breech*, and the upper the *fly*. It is necessary to bear in mind this distinction. We will now describe the

*Method of Raising the Lifts.*—If the base of the *breech* be fixed to the sill of the barrage, and we attempt to raise the lift by seizing the top of the *fly* with a hook, a resistance is at once experienced, that increases rapidly with the height of the fall in the navigable way, and becomes almost insurmountable when the fall attains a height of $0^{m} \cdot 30$.

With the movable lifts actually in use, the operation is performed in a totally different manner. Instead of proceeding as above, it is the lower part

573.



of the *breech* that is first raised; whereby the fall of water which, in the former instance, was an impediment, becomes, to a certain extent, an auxiliary, because it raises the woodwork of the lift as soon as the water has made its way beneath it. To this effect, the base of the *breech* is

provided with a stout iron handle. The keeper, entering a boat fitted for the purpose, seizes this handle with a hook; then, pulling, by degrees the *breech* of the lift rises from the platform, dragging with it its *chevalet*, and the latter its *buttress*, Fig. 573. When these three have arrived at the end of their course, the extremity of the buttress comes and rests against the shoe, and the gate remains suspended on its axis of rotation, while the *breech* is upheld by the boatman's hook. As soon as the hook is detached, if the *breech* be a little heavier than the *fly*, or if it be slightly pushed, the gate immediately turns upon its axis, and the *breech* rests against the sill of the weir. This is effectually what takes place; but in order to ensure precision and regularity in the working of the different parts, many other accessories are needed, the details of which our limits will not allow us to particularize.

There are twelve *barrages* between Paris and Montereau, of which the normal heights of the falls are as follows:—

| | Mètres. |
|---|---|
| Barrage of Port-à-l'Anglais .. .. .. .. .. | H = 2·40 |
| „ Albion .. .. .. .. .. .. .. | H = 1·85 |
| „ Evry .. .. .. .. .. .. .. | H = 1·54 |
| „ Coudray .. .. .. .. .. .. .. | H = 1·82 |
| „ La Citanguette .. .. .. .. .. | H = 1·43 |
| „ Vives-Eaux .. .. .. .. .. .. | H = 1·46 |
| „ Melun .. .. .. .. .. .. .. | H = 1·44 |
| „ La Cave .. .. .. .. .. .. .. | H = 1·97 |
| „ Samois .. .. .. .. .. .. .. | H = 2·00 |
| „ Champagne .. .. .. .. .. .. | H = 1·59 |
| „ La Madeleine .. .. .. .. .. | H = 1·64 |
| „ Varennes .. .. .. .. .. .. | H = 1·62 |

The extreme values are H = $2^{m}\cdot40$ and H = $1^{m}\cdot43$.

When the reserve is on a level with the top of a barrage, the real fall is equal to the normal fall, just given, less the surface incline of the water between that barrage and the one immediately below it. That incline may vary from 0 to $0^{m}\cdot15$. Moreover, it is necessary to deduct the thickness of the sheet of water surmounting the crest of the lower weir.

We regret that space will not allow us to enter into further details upon so interesting and important a subject. As we shall have occasion, however, to return to it again when speaking of flood-gates and canals, we must refer to those heads for more minute particulars touching the construction and working of the movable lift and the self-acting bascule gate. The lifts of a navigable way ought never to be self-acting, though the inconveniences likely to arise from their being so constructed would not be of any very serious nature. As regards the overfall, the case is different: there, on the contrary, it is of great importance that the lifts, swung *en bascule*, should be self-acting.

At the barrage of Conflans the overfall is composed of twenty lifts, each $1^{m}\cdot35$ high, $1^{m}\cdot20$ wide, and separated by spaces measuring $0^{m}\cdot10$. They are all self-acting, each gate swinging *en bascule*, and being regulated to resist a certain pressure by means of a counterpoise; so that, when by reason of a sudden increase of water the pressure becomes too great, they immediately yield, and, presenting a wider opening for the flood, prevent inundations, very much after the manner of the gates invented by M. Chaubart. It is, however, but an act of justice to state that the idea of a barrage with movable lifts was first due to M. Thénard, about the year 1840.

That gentleman, for a great many years chief engineer of the canal operations on the river Isle, had been unceasingly occupied in search of, and experimenting upon, the means of arriving at some efficient and practical mode of regulating, controlling, and utilizing the supply of water in rivers. He so far succeeded in this object, that he was enabled to sustain the waters of the river Isle at 7 ft. 4 in. above the level of the bed, procure a convenient draught of water to get boats up during dry weather, maintain them at this level sufficiently long so that the free flowing of the river was incapable of drawing them away, and, having arrived at this point, to restore the waters to their natural course in order not to expose the valleys to an overflow that would be prejudicial.

The first report, addressed to the Administration of Bridges and Highways, on the trials made by M. Thénard, is dated in 1831: it announced the good opinion formed of them by the inspector of the division. In 1839, for the purpose of verifying it, another commission, composed of Inspectors, general and divisional, of Bridges and Highways, was appointed by the Government. M. Thénard, having perfected with skill and success a happy idea of a provisional flood-gate, suggested to him by the divisional inspector, M. Mesnager, was able to render his system of *Barrage* more complete. On the 4th of July, 1841, the commission concluded their experiments and reported thereon.

Up to this time M. Thénard had only had occasion to apply his system to fixed existing barrages, raising the level of the water about 2 ft. 6 in. only. Confiding in the certainty of his system, however, he obtained authority to make a further trial, in which the retained body of water above the lower level was raised to a height of nearly 9 ft.

Among the authors who may be consulted are MM. Bresse, 'Cours de Mécanique Appliquée;' Lesbros, 'Expériences Hydrauliques sur les Lois de l'Ecoulement de l'Eau;' Chanoine, 'Notice sur les Barrages Mobiles;' Dubuat, 'Principes d'Hydraulique;' Chanoine and Lagrené, 'Mémoire sur les Barrages à Hausses Mobiles;' Mari; Graeff, 'Rapport sur la Forme et la Mode de Construction du Barrage d'Enfer sur le Furens,' Mémoires des Ponts et Chaussées, No. 134, 4e série; Gibbs, 'Cotton Cultivation, and the Barrage of Great Rivers,' crown 8vo, 1862; Breton, 'Mémoire sur les Barrages,' 4to, 1867.

TABLE I.—COEFFICIENTS OF EXPENDITURE.

Narrow-edged rectangular orifices, 0m·20 wide, and varying in height, discharging freely into the open air.

| | Loads upon the ridges of the Orifices. | COEFFICIENTS OF EXPENDITURE FOR ORIFICES WHOSE HEIGHTS ARE | | | | | |
|---|---|---|---|---|---|---|---|
| | | m. 0·20 | m. 0·10 | m. 0·05 | m. 0·03 | m. 0·02 | m. 0·01 |
| | m. | | | | | | |
| 1. Orifices completely isolated from the bottom and sides of the reservoir. | 0·02 | 0·572 | 0·596 | 0·616 | 0·639 | 0·660 | 0·695 |
| | 0·03 | 0·578 | 0·600 | 0·620 | 0·641 | 0·659 | 0·689 |
| | 0·04 | 0·582 | 0·603 | 0·623 | 0·640 | 0·659 | 0·684 |
| | 0·06 | 0·587 | 0·607 | 0·626 | 0·639 | 0·657 | 0·677 |
| | 0·10 | 0·592 | 0·611 | 0·630 | 0·637 | 0·655 | 0·667 |
| | 0·20 | 0·598 | 0·615 | 0·631 | 0·634 | 0·649 | 0·655 |
| | 0·30 | 0·600 | 0·616 | 0·630 | 0·632 | 0·645 | 0·650 |
| | 0·40 | 0·602 | 0·617 | 0·629 | 0·631 | 0·642 | 0·646 |
| | 0·60 | 0·604 | 0·617 | 0·627 | 0·630 | 0·638 | 0·641 |
| | 1·00 | 0·605 | 0·615 | 0·625 | 0·627 | 0·632 | 0·629 |
| | 1·50 | 0·602 | 0·611 | 0·619 | 0·621 | 0·620 | 0·617 |
| | 2·00 | 0·601 | 0·607 | 0·613 | 0·613 | 0·613 | 0·613 |
| | 3·00 | 0·601 | 0·603 | 0·606 | 0·607 | 0·608 | 0·609 |
| 2. Orifices whose lower surface is not contracted; i.e. is on a level with the bottom of the reservoir. | 0·02 | 0·599 | 0·624 | 0·664 | 0·691 | 0·703 | 0·756 |
| | 0·03 | 0·603 | 0·629 | 0·665 | 0·687 | 0·702 | 0·747 |
| | 0·04 | 0·605 | 0·633 | 0·666 | 0·686 | 0·701 | 0·741 |
| | 0·06 | 0·610 | 0·637 | 0·667 | 0·686 | 0·699 | 0·732 |
| | 0·10 | 0·615 | 0·643 | 0·669 | 0·684 | 0·698 | 0·722 |
| | 0·20 | 0·621 | 0·648 | 0·670 | 0·681 | 0·696 | 0·712 |
| | 0·30 | 0·622 | 0·648 | 0·670 | 0·681 | 0·695 | 0·709 |
| | 0·40 | 0·623 | 0·648 | 0·669 | 0·681 | 0·695 | 0·706 |
| | 0·60 | 0·624 | 0·648 | 0·668 | 0·679 | 0·693 | 0·703 |
| | 1·00 | 0·624 | 0·647 | 0·666 | 0·676 | 0·692 | 0·701 |
| | 1·50 | 0·624 | 0·644 | 0·665 | 0·675 | 0·687 | 0·697 |
| | 2·00 | 0·619 | 0·641 | 0·664 | 0·675 | 0·683 | 0·693 |
| | 3·00 | 0·614 | 0·639 | 0·662 | 0·675 | 0·680 | 0·689 |
| 3. Orifices whose vertical sides are not contracted; i.e. are in the same plane as the sides of the reservoir. | 0·02 | .. | .. | 0·655 | .. | .. | 0·715 |
| | 0·03 | .. | .. | 0·653 | .. | .. | 0·706 |
| | 0·04 | 0·649 | .. | 0·651 | .. | .. | 0·699 |
| | 0·06 | 0·647 | .. | 0·648 | .. | .. | 0·691 |
| | 0·10 | 0·645 | .. | 0·645 | .. | .. | 0·683 |
| | 0·20 | 0·641 | .. | 0·642 | .. | .. | 0·675 |
| | 0·30 | 0·639 | .. | 0·642 | .. | .. | 0·671 |
| | 0·40 | 0·639 | .. | 0·641 | .. | .. | 0·668 |
| | 0·60 | 0·638 | .. | 0·639 | .. | .. | 0·665 |
| | 1·00 | 0·638 | .. | 0·634 | .. | .. | 0·658 |
| | 1·50 | 0·637 | .. | 0·627 | .. | .. | 0·651 |
| | 2·00 | 0·636 | .. | 0·621 | .. | .. | 0·647 |
| | 3·00 | 0·634 | .. | 0·614 | .. | .. | 0·644 |
| 4. Orifices without any contraction, either of the sides or of the bottom. | 0·02 | .. | .. | .. | .. | .. | .. |
| | 0·03 | .. | .. | .. | .. | .. | .. |
| | 0·04 | .. | .. | .. | .. | .. | .. |
| | 0·06 | .. | .. | 0·699 | .. | .. | .. |
| | 0·10 | .. | .. | 0·696 | .. | .. | .. |
| | 0·20 | 0·708 | .. | 0·693 | .. | .. | .. |
| | 0·30 | 0·687 | .. | 0·691 | .. | .. | .. |
| | 0·40 | 0·682 | .. | 0·690 | .. | .. | .. |
| | 0·60 | 0·679 | .. | 0·688 | .. | .. | .. |
| | 1·00 | 0·676 | .. | 0·685 | .. | .. | .. |
| | 1·50 | 0·672 | .. | 0·681 | .. | .. | .. |
| | 2·00 | 0·668 | .. | 0·680 | .. | .. | .. |
| | 3·00 | 0·665 | .. | 0·678 | .. | .. | .. |

## Table II.

Narrow-edged rectangular orifices, $0^m \cdot 20$ in width, and varying in height, and continued outwards by a rectangular, horizontal, and open channel, of the same width as the orifice.

| | Loads upon the ridge of the orifices. | Coefficients of Expenditure for Orifices whose Heights are | | | | | |
|---|---|---|---|---|---|---|---|
| | | m. 0·20 | m. 0·10 | m. 0·05 | m. 0·03 | m. 0·02 | m. 0·01 |
| | m. | | | | | | |
| 1. Orifices completely isolated from the bottom and sides of the reservoir. | 0·02 | 0·480 | 0·484 | 0·488 | 0·501 | .. | 0·599 |
| | 0·03 | 0·493 | 0·507 | 0·525 | 0·551 | .. | 0·626 |
| | 0·04 | 0·503 | 0·527 | 0·555 | 0·598 | .. | 0·645 |
| | 0·06 | 0·518 | 0·557 | 0·594 | 0·632 | .. | 0·667 |
| | 0·10 | 0·542 | 0·586 | 0·624 | 0·633 | .. | 0·671 |
| | 0·20 | 0·574 | 0·606 | 0·631 | 0·632 | .. | 0·664 |
| | 0·30 | 0·591 | 0·612 | 0·629 | 0·631 | .. | 0·658 |
| | 0·40 | 0·597 | 0·615 | 0·626 | 0·630 | .. | 0·652 |
| | 0·60 | 0·600 | 0·615 | 0·625 | 0·628 | .. | 0·644 |
| | 1·00 | 0·601 | 0·615 | 0·624 | 0·625 | .. | 0·631 |
| | 1·50 | 0·601 | 0·612 | 0·619 | 0·620 | .. | 0·618 |
| | 2·00 | 0·601 | 0·607 | 0·613 | 0·613 | .. | 0·613 |
| | 3·00 | 0·601 | 0·603 | 0·606 | 0·607 | .. | 0·609 |
| 2. Orifices whose lower surface is not contracted. | 0·02 | 0·480 | .. | 0·487 | .. | .. | 0·616 |
| | 0·03 | 0·493 | .. | 0·526 | .. | .. | 0·642 |
| | 0·04 | 0·502 | .. | 0·552 | .. | .. | 0·660 |
| | 0·06 | 0·517 | .. | 0·583 | .. | .. | 0·676 |
| | 0·10 | 0·538 | .. | 0·605 | .. | .. | 0·682 |
| | 0·20 | 0·566 | .. | 0·617 | .. | .. | 0·679 |
| | 0·30 | 0·580 | .. | 0·622 | .. | .. | 0·676 |
| | 0·40 | 0·587 | .. | 0·625 | .. | .. | 0·673 |
| | 0·60 | 0·595 | .. | 0·627 | .. | .. | 0·670 |
| | 1·00 | 0·600 | .. | 0·628 | .. | .. | 0·665 |
| | 1·50 | 0·602 | .. | 0·627 | .. | .. | 0·657 |
| | 2·00 | 0·602 | .. | 0·623 | .. | .. | 0·654 |
| | 3·00 | 0·601 | .. | 0·618 | .. | .. | 0·652 |
| 3. Orifices whose lower surface is isolated from the bottom, and whose vertical sides project $0^m \cdot 02$ from the sides of the reservoir. | 0·02 | 0·496 | .. | 0·557 | .. | .. | 0·675 |
| | 0·03 | 0·510 | .. | 0·577 | .. | .. | 0·683 |
| | 0·04 | 0·522 | .. | 0·592 | .. | .. | 0·688 |
| | 0·06 | 0·539 | .. | 0·611 | .. | .. | 0·693 |
| | 0·10 | 0·563 | .. | 0·628 | .. | .. | 0·694 |
| | 0·20 | 0·591 | .. | 0·637 | .. | .. | 0·684 |
| | 0·30 | 0·607 | .. | 0·636 | .. | .. | 0·677 |
| | 0·40 | 0·615 | .. | 0·635 | .. | .. | 0·673 |
| | 0·60 | 0·625 | .. | 0·635 | .. | .. | 0·669 |
| | 1·00 | 0·628 | .. | 0·635 | .. | .. | 0·663 |
| | 1·50 | 0·627 | .. | 0·634 | .. | .. | 0·656 |
| | 2·00 | 0·626 | .. | 0·634 | .. | .. | 0·651 |
| | 3·00 | 0·624 | .. | 0·632 | .. | .. | 0·648 |
| 4. Orifices whose lower surface is not contracted, and whose vertical sides project $0^m \cdot 02$ from the sides of the reservoir. | 0·02 | .. | .. | 0·512 | .. | .. | 0·625 |
| | 0·03 | .. | .. | 0·543 | .. | .. | 0·651 |
| | 0·04 | 0·518 | .. | 0·566 | .. | .. | 0·667 |
| | 0·06 | 0·536 | .. | 0·595 | .. | .. | 0·686 |
| | 0·10 | 0·560 | .. | 0·621 | .. | .. | 0·697 |
| | 0·20 | 0·589 | .. | 0·637 | .. | .. | 0·698 |
| | 0·30 | 0·603 | .. | 0·643 | .. | .. | 0·696 |
| | 0·40 | 0·613 | .. | 0·646 | .. | .. | 0·694 |
| | 0·60 | 0·623 | .. | 0·648 | .. | .. | 0·690 |
| | 1·00 | 0·630 | .. | 0·649 | .. | .. | 0·685 |
| | 1·50 | 0·633 | .. | 0·647 | .. | .. | 0·679 |
| | 2·00 | 0·632 | .. | 0·644 | .. | .. | 0·674 |
| | 3·00 | 0·630 | .. | 0·639 | .. | .. | 0·670 |

TABLE III.

Narrow-edged rectangular overfalls, 0m·20 wide,
- discharging freely into the open air .. .. .. .. .. (A)
- outwardly extended by means of an open horizontal channel of equal section with the orifice .. .. .. .. .. .. (B)

The arrangements A and B may present the variations defined at 1, 2, and 3, Table I., and 3 and 4, Table II., when the rectangular orifices are closed at the top.

| Loads upon the Sill of the Overfall. | Coefficients of Expenditure for overfalls presenting the arrangement A, with its variation. | | | | Coefficients of Expenditure for overfalls presenting the arrangement B, with its variation. | | | |
|---|---|---|---|---|---|---|---|---|
| | Tab. I. 1 | Tab. I. 2 | Tab. I. 3 | Tab. II. 4 | Tab. I. 1 | Tab. I. 2 | Tab. II. 3 | Tab. II. 4 |
| m. | | | | | | | | |
| 0·01 | 0·424 | 0·384 | 0·492 | 0·292 | .. | .. | 0·395 | .. |
| 0·02 | 0·417 | 0·402 | 0·473 | 0·318 | 0·196 | 0·208 | 0·383 | 0·175 |
| 0·03 | 0·412 | 0·410 | 0·459 | 0·337 | 0·234 | 0·232 | 0·373 | 0·205 |
| 0·04 | 0·407 | 0·411 | 0·449 | 0·352 | 0·263 | 0·251 | 0·365 | 0·234 |
| 0·05 | 0·404 | 0·411 | 0·442 | 0·362 | 0·278 | 0·268 | 0·360 | 0·260 |
| 0·06 | 0·401 | 0·410 | 0·437 | 0·370 | 0·286 | 0·281 | 0·355 | 0·276 |
| 0·07 | 0·398 | 0·409 | 0·435 | 0·375 | 0·292 | 0·288 | 0·352 | 0·285 |
| 0·08 | 0·397 | 0·409 | 0·434 | 0·379 | 0·297 | 0·294 | 0·349 | 0·291 |
| 0·09 | 0·396 | 0·409 | 0·434 | 0·380 | 0·301 | 0·298 | 0·347 | 0·295 |
| 0·10 | 0·395 | 0·408 | 0·434 | 0·382 | 0·304 | 0·302 | 0·345 | 0·299 |
| 0·12 | 0·394 | 0·408 | 0·434 | 0·383 | 0·309 | 0·308 | 0·343 | 0·306 |
| 0·14 | 0·393 | 0·408 | 0·434 | 0·383 | 0·313 | 0·312 | 0·341 | 0·311 |
| 0·16 | 0·393 | 0·407 | 0·433 | 0·384 | 0·316 | 0·316 | 0·340 | 0·315 |
| 0·18 | 0·392 | 0·406 | 0·432 | 0·383 | 0·317 | 0·319 | 0·339 | 0·319 |
| 0·20 | 0·390 | 0·405 | 0·432 | 0·383 | 0·319 | 0·323 | 0·338 | 0·322 |
| 0·22 | 0·386 | 0·405 | 0·430 | 0·382 | 0·320 | 0·325 | 0·337 | 0·325 |
| 0·25 | 0·379 | 0·404 | 0·428 | 0·381 | 0·321 | 0·329 | 0·336 | 0·329 |
| 0·30 | 0·371 | 0·403 | 0·424 | 0·378 | 0·324 | 0·332 | 0·334 | 0·332 |

BARREL. Fr., *Tonneau;* Ger., *Fass;* Ital., *Barile, Bariglione;* Span., *Barril.*

A barrel is a round vessel or cask, of more length than breadth, and bulging in the middle, made of staves and headings, and bound with hoops.

The term is also applied to a tube, or to any hollow cylinder, as the barrel of a *gun*, the barrel of a *pump*, and so on.

BARREL-CURB. Fr., *Margelle;* Ger., *Senkrahmen;* Ital., *Appoggio impiegato nella costruzione dei pozzi;* Span., *Mardelle.*

A barrel-curb, or well-curb, is an open cylinder, about 3 ft. 6 in. or 4 ft. in length, formed of strips of wood nailed round horizontal ribs of elm, and used as a mould in well-sinking to keep the well cylindrical during the process of sinking. When the required depth has been attained, this cylinder is usually left in the bottom of the well, under the steming, brickwork being built up under the horizontal ribs.

BARREL-DRAIN. Fr., *Tranchée en berceau;* Ger., *Tonnenförmiger Abzugscanal;* Ital., *Fogna cilindrica;* Span., *Alcantarilla Cilíndrica.*

A barrel-drain is a brick or stone drain of cylindrical form.

BARRIER. Fr., *Barrière;* Ger., *Barriere;* Ital., *Palizzata;* Span., *Barrera.*

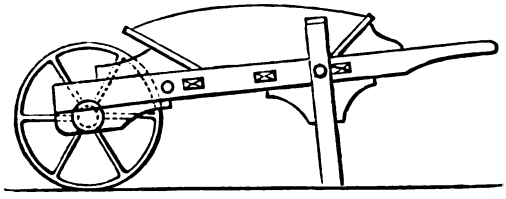
In *fortification* a barrier is a kind of fence made in a passage or retrenchment to stop an enemy. It is usually a palisade or stockade.

BARROW. Fr., *Brouette;* Ger., *Schubkarren;* Ital., *Carriuola;* Span., *Carretilla de mano.*

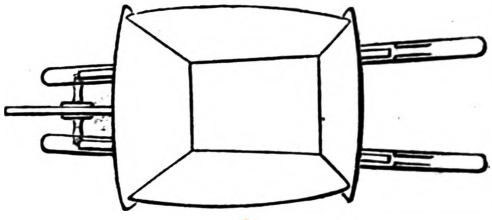
A barrow is a light, small carriage, borne or moved by hand.

The body of the excavator's barrow, Figs. 574, 575, is spread wide open, and the sides are much inclined; the centre of gravity of the load is therefore situated much lower, with respect to the

574.



575.



handles, than in the ordinary barrow, which renders it steadier and easier to wheel. The contents are discharged by inclining the barrow at an angle of 45°, and supporting it constantly on the wheel. The nave of the wheel is prolonged on each side, and serves as an axle, the periphery of which is about 1 in. in thickness and rounded on the edge.

BARS, GUARD. FR., *Garde-fou*; GER., *Fenster Vergitterung*; ITAL., *Sbarra*.

Usually wrought-iron bars in front of windows, about $\frac{7}{8}$ in. in diameter, if round, or $\frac{3}{4}$ in. if square, spaced about 5 in. apart, and fixed perpendicularly through horizontal rails of flat bar-iron, $1\frac{1}{4}$ in. wide by $\frac{3}{8}$ in. thick, built into the jambs of the window: the ends of the bars at the bottom should be let into the stone sill, and run with lead.

BASCULE BRIDGES. FR., *Pont-levis*; GER., *Zugbrücke*; ITAL., *Ponte levatoio*; SPAN., *Puente-báscula*.

See DRAWBRIDGES.

BASEMENT. FR., *Soubassement*; GER., *Fundament, Untere Theil*; ITAL., *Basamento*; SPAN., *Bajamente, Planta baja*.

See BUILDING.

BASE-LINES. FR., *Lignes de base*; GER., *Grundlinie*; ITAL., *Base di triangolazione*; SPAN., *Base trigonométrica*.

See GEODESY.

BASE-PLATE. FR., *Plaque de fondation*; GER., *Grundplatte*; ITAL., *Piastra di fondazione*; SPAN., *Plancha de cimiento*.

The foundation-plate of heavy machinery, as of the steam-engine, is termed the base-plate; the *bed-plate*.

BASIN. FR., *Bassin*; GER., *Schiffsdocke*; ITAL., *Bacino*; SPAN., *Pantano, dique*.

Any hollow place containing water, as a dock for ships, is called a basin. See DOCKS.

BASKET-HANDLED ARCH. FR., *Arc en anse de panier*; GER., *Stichbogen*; ITAL., *Arco scemo*; SPAN., *Arco elíptico*.

Any arch less than a semicircle on the same chord is called a basket-handled arch, hence all semi-elliptic arches are included in the term.

BASTARD ASHLAR. FR., *Moëllon gisant*; GER., *Pläner*; ITAL., *Pietra rozza*.

Bastard ashlar are stones intended for ashlar-work, which are merely rough scabbled to the required size at the quarry; or the face-stones of a rubble wall, which are selected, squared, and dressed, to resemble ashlar.

BASTARD STUCCO. FR., *Stuc mêlé de mastic*; GER., *Kalkmörtel mit feinem Sande versetzt*; ITAL., *Stucco rozzo*.

The finishing coat in plastering when prepared for paint is termed bastard stucco. It is composed of similar stuff to that used for trowelled stucco, with the addition of a small portion of hair, but is accompanied with less labour, not being floated; it is generally employed in three-coat work.

BASTARD-TOOTHED FILE. FR., *Grosse lime*; GER., *Bestossfeile*; ITAL., *Lima bastarda*; SPAN., *Lima*.

See HAND-TOOLS.

BASTION. FR., *Bastion*; GER., *Bastion, Bollwerk*; ITAL., *Bastione*; SPAN., *Balnarte*.

See FORTIFICATION.

BAT. FR., *Morceau de brique*; GER., *Schieferstein*; ITAL., *Pezzo di mattone*; SPAN., *Medio ladrillo*.

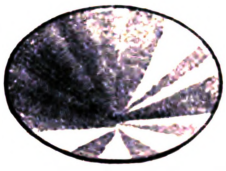
The half of a brick is usually termed a bat. Other portions are named according to the size, as a quarter bat, three-quarter bat, and so on.

BATEA. FR., *Cuvette pour laver l'or*; GER., *Waschschüssel für Gold*; ITAL., *Bacinella per lavare l'oro*; SPAN., *Batea*.

A batea is a conical-shaped dish, Fig. 576, employed for washing gold and pulverized samples of gold quartz.

From the general irregularity of the produce of quartz in gold mines, it is impossible to ascertain the average yield of vein-stuff without crushing and experimenting on large quantities; but the most usual method of judging approximately of the value of rock, is to pulverize a small quantity and wash the resulting powder in a batea or horn spoon. In selecting the rock for this purpose, it is evidently of the greatest importance that it should represent a fair average of the vein or streak from which it is taken, and consequently several hundred-weights should be broken from the whole area of the exposed surface, taking care that every part be represented by samples of nearly equal weights. The whole must now be broken by a hammer on an iron plate, into pieces of about the size of walnuts. The resulting heap is then carefully mixed, by turning over with a shovel, and subsequently cut through the middle, so as to leave a trench through its centre, extending to the floor on which it has been placed. The two sides are afterwards carefully scraped down, and removed as a representative sample on which the yield of the vein is to be estimated. For the purpose of a rough approximation, this may be at once pulverized in a mortar or otherwise, and its contents judged of in accordance with the results obtained by washing. Where, however, greater accuracy is aimed at, and the original heap contained a large quantity of broken rock, at least a hundred-weight should be scraped from the sides of the cutting, and this, after being further reduced to the size of peas, must again be cut through, and a sample of about 4 lbs. obtained, by the means employed in the first instance, as the final sample. This is pulverized in a mortar, and the whole passed through a sieve of wire gauze, of forty holes to the lineal inch, after which it is ready for treatment, either by washing or assay.

576.



The most accurate results are obtained by carefully washing a 4-lb. sample in the batea, Fig. 576, which is about 20 in. in diameter, and $2\frac{1}{2}$ in. in depth.

BATH. FR., *Bain*; GER., *Bad*; ITAL., *Bagno*; SPAN., *Baño*.

See WASHHOUSES and BATHS.

BATH-METAL. FR., *Tombac*; GER., *Tomback*; ITAL., *Lega di Bath*; SPAN., *Tumbaja*.

Bath-metal is an alloy consisting of $4\frac{1}{2}$ oz. zinc and 1 lb. copper. See ALLOYS.

BATTEN. Fr., *Volige*; Ger., *Dünnes Brett*; Ital., *Tavola stretta, Listello*; Span., *Astilla.*

Batten is a term applied to sawn timber under 3 in. in thickness, when the width is 7 in., to distinguish it from other widths, such as *deals* and *planks.*

The term *batten* is also applied to boards in long lengths of less than 7 in. wide, though seldom more than 2 or 3 in. in width—the thickness varying from ½ in. to 1½ in., according to the purpose for which they are intended.

BATTENING. Fr., *Construction en volige*; Ger., *Schalwerk*; Ital., *Costruzione di listelli.*

Narrow boards or battens fixed to walls, intended to be papered over canvas or to receive the laths for plastering—also battens nailed on the rafters of a roof to receive the slating—are called battening.

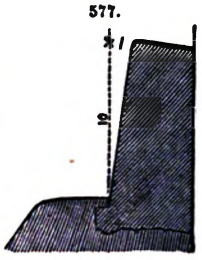
Wall-battens should be spaced about 12 in. apart, and are generally 2½ or 3 in. wide, and ¾ to 1¼ in. thick.

Slate-battens must be spaced to correspond with the gauge of the slate. They should be from 2½ to 3 in. wide, and from ¾ to 1¼ in. in thickness, according to the strength required.

BATTER. Fr., *Talus*; Ger., *Verjungung*; Ital., *Inclinazione di muro Scarpa*; Span., *Inclinacion, talud.*

In building, batter is a term employed to signify leaning back; it is usually expressed by the ratio of the departure from the perpendicular to the height, as 1 in 10, Fig. 577, which means that for every 10 ft. in height the wall batters 1 ft.

577.



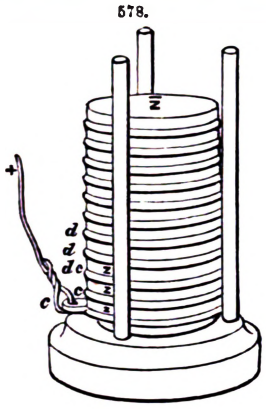
Retaining walls are sometimes battered on the face to the extent of 1 in 5; latterly, however, 1 in 10 has become more general, as when the batter is great the joints of the sloping wall hold the wet, which soon finds its way into the work: it is on this account that most engineers prefer walls with a vertical face, or at most with a very slight batter.

BATTERY. Fr., *Batterie galvanique*; Ger., *Galvanische Batterie*; Ital., *Batteria Galvanica.*

When a series of voltaic elements, cells, couples, or pairs, are arranged in such a manner that the zinc of one element is in connection with the copper of another element; the zinc of this with the copper of a third, and so on; such an arrangement is termed a Galvanic or Voltaic Battery.

The earliest galvanic battery was constructed by Volta in 1800. It consisted of an insulated plate, Fig. 578, upon which was placed a series of discs of copper and of zinc soldered together. Above the copper of the first disc was placed a disc of cloth *d*, saturated with acidulated water; upon the disc of cloth was then laid another metallic disc. These discs were thus alternately laid one upon another, until a pile, Fig. 579, had been built up, care being taken to lay them the same way. To the ends of this pile were attached wires *p* and *n*, which, when connected in any way, set in motion a current of electricity.

578.

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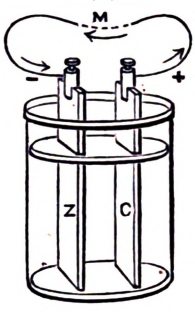


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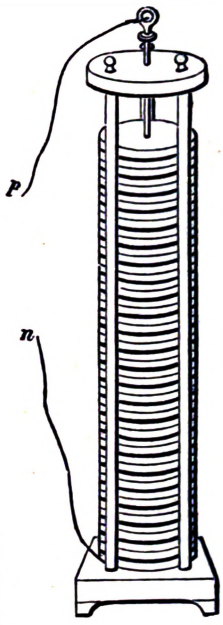


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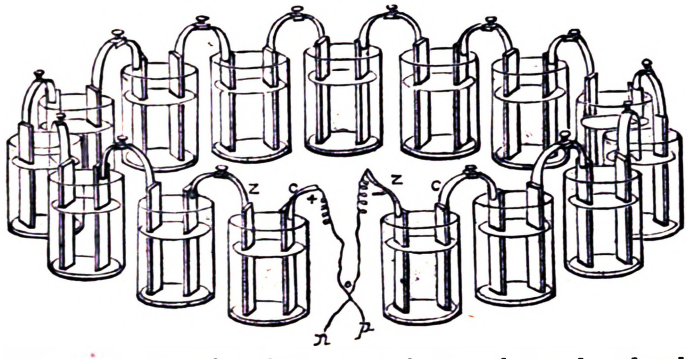



The piles constructed in this way were, however, but weak, and useless for experiments which lasted any length of time; for as the number of elements was augmented, the weight of the upper discs pressed the liquid from the lower discs, which became dry, and so lost their conductibility.

This led Volta to invent the improved modification shown in Fig. 581, which he called the *couronne de tasses*, or crown of cups. Instead of the damp cloth of the pile, a number of jars, arranged in a circle, and filled with acidulated water, are employed. The jars communicate successively one with the other by means of metallic arches formed of a plate of zinc soldered to a plate of copper; the copper of each arch being plunged into the jar which precedes it, and the zinc into the jar which follows it. The two jars which form the extremities of the series receive respectively a plate of zinc Z, and a plate of copper C, to each of which is fastened a conducting-wire. The first corresponds to the negative pole and the second to the positive pole.

To comprehend the principle of this battery, we will suppose that two plates, cut, one Z from a sheet of zinc, and the other C from a sheet of copper, Fig. 580, are placed, without contact with each other, in a jar containing slightly acidulated water. To the upper edges of the plates let two pieces of wire be fastened. In this state the apparatus will manifest no development of the electric fluid; but if the ends of the wires be brought into contact at M, an electric current will be set in motion, passing through the wires from the point where the wire is fastened to the copper C, to the point where the other wire is soldered to the zinc Z. The current will continue to flow so long as the ends of the wires are in contact, but the moment the ends are separated the current ceases.

It will be seen that the electric fluid is evolved by the combination of three bodies—the zinc, the copper, and the acidulated solution in which they were immersed. The production of the current depends on the chemical action of the solution on the zinc. That metal being very susceptible of oxidation, decomposes the water which is in contact with it. One constituent of the water combining with the zinc produces a compound called the oxide of zinc, and this oxide entering again into combination with the acid which the water holds in solution, forms a soluble salt. If the acid, for example, be sulphuric acid, this salt will be the sulphate of the oxide of zinc; and as fast as it is produced it will be dissolved in the water in which the plates were immersed. The copper not being as susceptible of chemical action as the zinc, remains comparatively unaffected by the solution; but the hydrogen evolved in the decomposition of the water collects upon its surface, after which it rises and escapes in bubbles at the surface of the solution.

It is to this chemical action upon the zinc that the production of the electric current is due. If a similar action had taken place in the same degree on the copper, a similar and equally intense electric current would be produced in the opposite direction; in that case the two currents would neutralize each other, and no electric effect would ensue. From this it will be seen that the efficacy of the combination must be ascribed to the fact that one of the two metals immersed in the solution is more oxidizable than the other, and that the energy of the effect and the intensity of the current will be so much the greater as the susceptibility of oxidation of one metal exceeds that of the other.

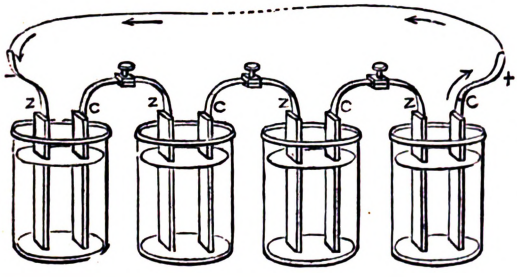
It appears, therefore, that the principle may be generalized, and that electricity will be developed and a current produced by any two metals similarly placed, which are oxidizable in different degrees. And, indeed, if two pieces of the same metal are differently acted upon, either by heat or chemically, a current of electricity will be produced on their being connected together.

Zinc being one of the most oxidizable metals, and being also sufficiently cheap and plentiful, is generally used for voltaic combinations. Silver, gold, and platinum are severally less susceptible of oxidation, and of chemical action generally, than copper, and would therefore answer voltaic purposes better, but are excluded by their greater cost, and by the fact that copper is found sufficient for all practical purposes. It is not, however, absolutely necessary that the inoxidizable plate C of the combination should be a metal. It is only necessary that it be a good conductor of electricity.

In certain voltaic combinations, charcoal properly solidified has therefore been substituted for copper, the solution being such as would produce a strong chemical action on copper. Each combination of two metals, or of one metal and charcoal, is called either a cell, a couple, an element, or a pair.

A series of jars, Fig. 582, when arranged in a similar manner to Volta's *couronne de tasses*, that is, the zinc of one jar in connection with the copper of the next jar, the order being zinc, acid, copper, zinc, acid, copper, and so on, is termed a battery, and by its means the effects produced by a single element are capable of being greatly increased. If, however, only one element is employed, it is in itself a battery.

582.

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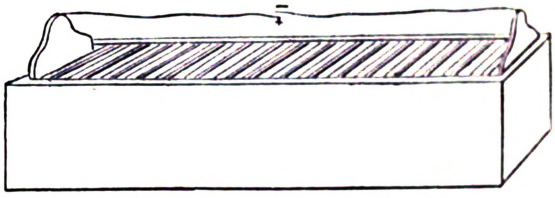
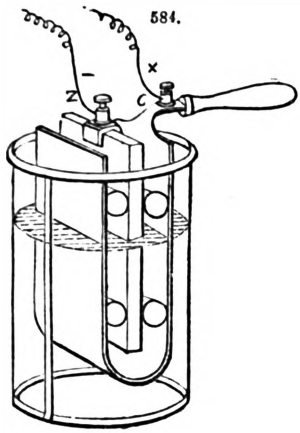


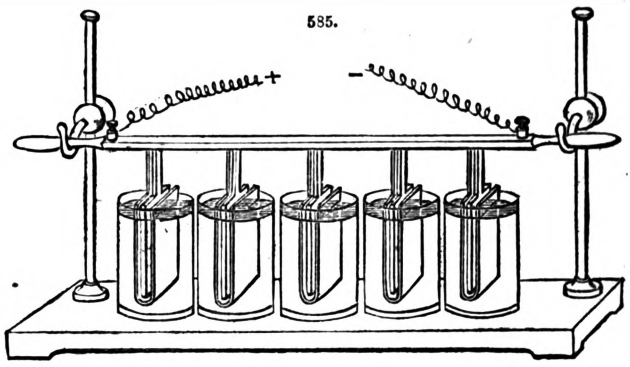

The part of a battery from which the current is supposed to proceed is called the positive pole, and the part towards which the current flows, the negative pole. These poles, shown at + and −, Fig. 582, are often termed electrodes, so that + would be the positive and — the negative electrode.

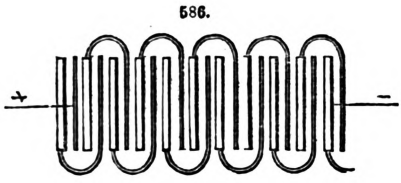
The arrangement of the *couronne de tasses*, and of batteries similarly constructed, was so cumbersome that they were soon superseded by the Trough battery, which is shown in Fig. 583. This

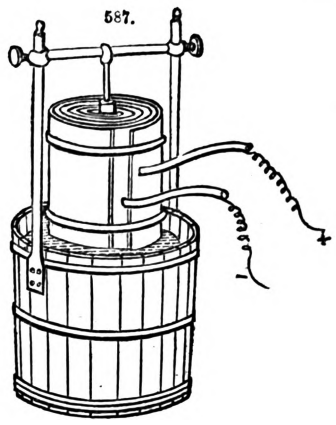
battery was invented by Cruickshank, and consists of a rectangular water-tight trough divided into cells by plates formed of zinc and copper soldered together. The cells are filled with acidulated water or a solution of salt and water; and two plates of copper, furnished with conducting-wires, are immersed in the last cell at each end. It was with a battery of this kind, composed of 3000 couples, that at the commencement of the present century Davy succeeded in decomposing potash and soda, and thus discovered potassium and sodium. The trough battery is rather inconvenient on account of its weight, and also through the wood of the case warping under the action of the acids.

The arrangement introduced by Wollaston is more convenient. An element of Wollaston's battery, Fig. 584, is composed of a plate of zinc Z, round which is bent a plate of copper C, actual contact being prevented by placing small pieces of wood or cork between the plates. When the element is to be put in operation, it is immersed in a vase containing acidulated water; the negative pole then establishes itself at the wire connected with the zinc, and the positive pole at the wire fastened to the copper. To unite several elements into a battery, it is necessary to connect the copper of each element with the zinc of the following. The elements thus connected can then be mounted on a stand, Fig. 585, and, when the battery is to be operated, plunged separately into vases containing the exciting liquid. The necessity of a vase for each of the elements of Wollaston's battery renders it cumbersome.




Muncke's battery removes this inconvenience, as by its means we can have a considerable number of elements in a small space. The plates of zinc and of copper are soldered together vertically, bent into the form of the letter U, and then fitted alternately one into the other, Fig. 586, in such a manner that the alternation of the metals is complete. Together the elements form a single system, which is fixed in a wooden frame, and, when required for use, immersed in a stone trough filled with acidulated water.

Batteries composed of a number of elements, as Muncke's battery, are especially applicable when the current encounters in its polar circuit any great resistance. When this resistance is weak, it is preferable to have the advantage of increasing the area of the surface of the elements rather than their number. This condition is realized by Dr. Hare's cylindrical battery, Fig. 587, which consists of a large sheet of zinc and one of copper, soldered together at one end. The sheets are rolled, without touching each other, round a cylinder of wood, and each is attached to metallic conducting-wires; the negative wire is that in connection with the zinc, and the positive wire that fastened to the copper.

When the apparatus is to be used, it is plunged into a tub containing acidulated water. When several of these elements are united in a battery, an apparatus is obtained, of which the caloric power is so great as to have obtained for it the name of a calorimotor.

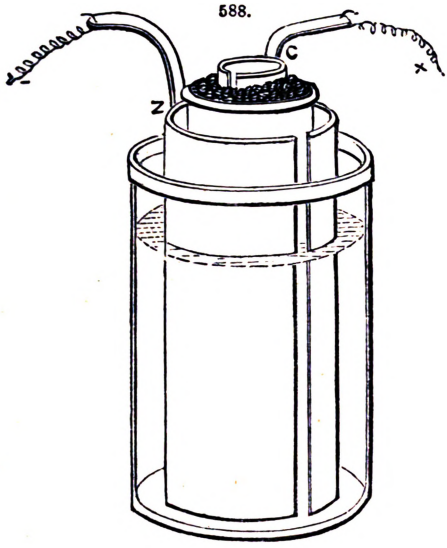
The batteries we have described present practically several serious inconveniences. The water being decomposed by the zinc, liberates hydrogen, which, charged with acid particles, is released

into the air, rendering in a very short time the surrounding atmosphere irrespirable. Besides this, the liberated hydrogen adheres as a film on the surface of the copper, presenting a great resistance to the current, and sensibly diminishing its intensity. Lastly, this film has a variable thickness, from which results a perpetual variation in the intensity of the current itself. These inconveniences, however, disappear in a greater or less degree in batteries operated by two liquids.

*Daniell's Battery.*—An element of Daniell's battery, Fig. 588, consists of an outer jar containing acidulated water in which is immersed a cylinder of zinc Z, in the interior of which is placed a porous earthenware pot, filled with a solution of sulphate of copper which surrounds a cylinder of copper C. The conducting-wire attached to the zinc, Fig. 588, corresponds to the negative pole of the element.

It is easily seen that in this arrangement the film of hydrogen which acts so disadvantageously in ordinary batteries, no longer exists; and the metal, following the same direction as positive electricity, deposits itself upon the copper cylinder. The disengagement of the hydrogen is replaced by a decomposition of the copper, which does not change the physical condition of the system. The action of this battery is very regular, it lasts a long time without renewal, and the surrounding atmosphere is not sensibly affected by its fumes.

588.

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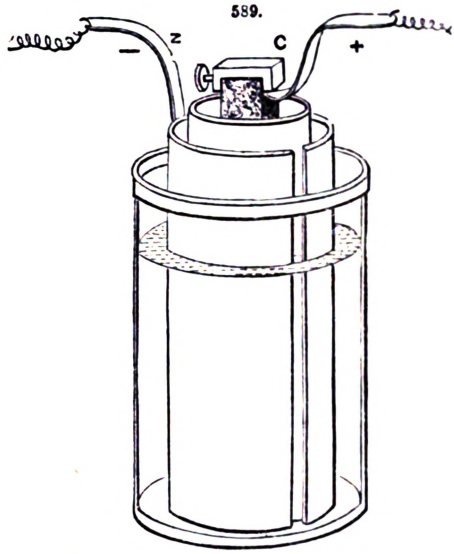
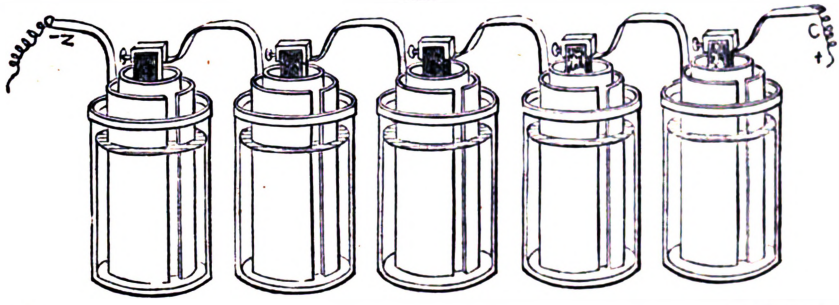



Amongst the causes which vary the intensity of the current in this battery is the change in the nature of the liquids, the acidulated water becoming charged more and more with sulphate of zinc; and the decomposition of the sulphate of copper. Experience has shown that the first circumstance does not affect the intensity of the current in any sensible degree. To remedy the second, in proportion as the sulphate of copper is decomposed, fresh portions of that salt are added; and for this purpose there is a sort of perforated flange on the upper part of the copper cylinder, which is kept filled with crystals of sulphate of copper.

*Bunsen's Battery* consists of a vase, Fig. 589, containing dilute sulphuric acid, in which is placed a plate of zinc Z as in Daniell's battery; but in the porous pot is poured nitric acid at 40°, and, instead of the copper, a prism of charcoal, made from the residuum taken from the retorts of gas-works, is used.

To form a battery, Fig. 590, the carbon of one element is united with the zinc of the following element, by means of clamps, the positive pole evidently corresponding to the last carbon, and the negative pole to the last zinc.

590.




In Bunsen's battery, the hydrogen liberated by the decomposition of the water decomposes in its turn the nitric acid in which the carbon is immersed; the result is that hyponitric acid is formed, which gradually dissolves, and never shows itself in the form of bubbles.

Bunsen's battery is only a modification of a battery previously invented by Grove, in which the place of the carbon was occupied by a plate of platinum; but the high price of this metal caused the use of Grove's battery to be very limited. Several inventors had thought of replacing the platinum plate by charcoal; and a few batteries of this description were in use at the time Bunsen's arrangement was introduced.

It should be noticed that a great inconvenience attends all batteries in which nitric acid is employed, owing to the diffusion of nitrous vapour which vitiates the surrounding air.

When a battery is in action, the work produced at the poles corresponds to the oxidation or consumption of the zinc, in a similar manner to the caloric engine, where the work performed is in proportion to the amount of coal consumed. If ordinary zinc is used, in batteries furnished with acidulated water, the zinc is always found attacked, whether the battery is in operation or not; but this does not occur if chemically pure zinc is used. However, there is no occasion to use pure zinc if amalgamated zinc, which is easily made, is employed.

The amalgamation of the zinc is best effected by dipping it in dilute sulphuric acid, and then rubbing it over with mercury, or by immersing it in a solution of a salt of mercury, and afterwards rubbing it briskly, when the amalgamation will be complete.

There have been numerous batteries contrived, which we do not notice, as their description would be of no interest. We only mention the Bichromate of Potash battery, which is frequently made use of in the current for the purpose of exciting various electrical machines. The element consists of a spherical-shaped bottle, with a broad neck, containing a solution of $\frac{1}{10}$ bichromate of potash, added to an equal quantity of sulphuric acid. Into the liquid is plunged a double plate of zinc, Fig. 591, in the interior of which is arranged a plate of charcoal, which answers to the positive pole. When it is desired to suspend the action of the battery, the plate of zinc is raised, so as to prevent its contact with the liquid.

The work produced by chemical action is not the only means of obtaining a galvano-electric current; the same result may be arrived at by the action of heat. This development of electricity by heat was discovered by Seebeck, of Berlin, in 1821, and is called *thermo-electricity*.

To make a thermo-electric couple, a plate of copper, Fig. 592, is bent round and soldered at its two ends to a cylinder of bismuth; we have thus a sort of rectangular figure, three sides of which are made by the plate of copper, and the fourth by the bismuth cylinder. The apparatus must be arranged in such a manner that the long sides of the rectangle are nearly in the magnetic meridian; and in the interior of the apparatus is placed a magnetic needle. If one of the compound corners of the circuit, where the two metals are joined, is heated with a spirit-lamp, Fig. 592, the needle is deflected; this denotes the production of an electric current which is directed in the copper plate from the warm corner to the cold corner. If, instead of heating the corner, it had been refrigerated with ice, it would also have produced a current, but in an opposite direction.

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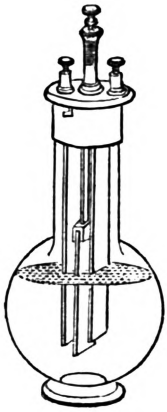

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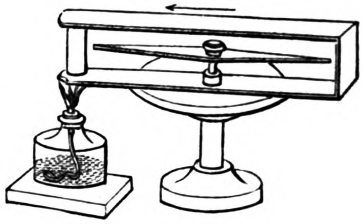

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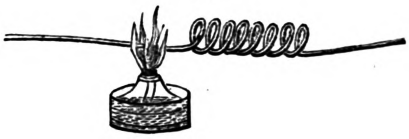


Although this experiment is especially sensible with bismuth and antimony, it will succeed with any of the metals. It is also not absolutely necessary to heat the point in the circuit where the two metals join, since if an elevation of temperature takes place at any point where a perfect similarity of structure does not exist, a current immediately manifests itself. This important fact is demonstrated by various experiments. Take, for example, a piece of platinum wire which has been twisted into a knot, and heat it near the twist; it will produce a current of electricity, the force of which may be observed by placing the extremities of the wires in connection with a galvanometer. The current, it will be seen, changes from one side to the other of the knot as either side is heated.

The same result will occur if a portion of the wire is coiled into a spiral, Fig. 593, and treated in the same manner.

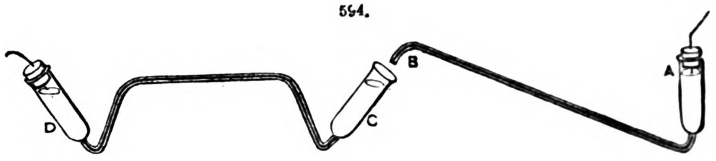
In metals which are, similar to bismuth, not homogeneous, it is very common to observe thermo-electric currents.

It should be noticed that to a difference in structure, and to no other circumstance, as, for example, a change of dimensions, is this phenomenon attributed. When the molecular construction is the same on both sides of the heated point, there will be no current manifested. The two following experiments made by M. Magnus are decisive on this head. He reduced a copper cylinder in the middle until it was only the thickness of a fine wire; on heating the metal at the place where the sudden change in its diameter occurred, he did not observe any current, although there must have been a difference in the diffusion of the electricity from one side to the other of this point.

For his second experiment, Magnus took two tubes, A B and C D, Fig. 594, and filled them with mercury: the extremities A and D being connected with the wires of a galvanometer. The mercury contained in C was heated, and the extremity of the tube B plunged into it. In this case also no current was observed. Yet if a difference of structure is necessary to produce a current,

this difference may be very insignificant. So that if the extremities of the two platinum wires were bent into hooks, and one of them after being heated laid upon the other, no effect would be produced, because the action of heat upon the platinum could not make it undergo any modification.

594.



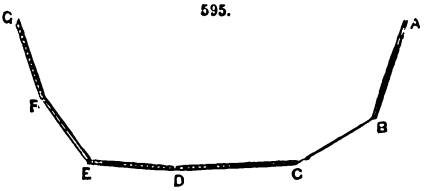

But if the experiment is repeated with copper wires, a current will occur, the action of heat having quickly produced a film of oxide which has modified the constitution of the metal.

It follows from this that the action of heat has the effect of exciting in various bodies, and particularly in metals, the movement of fluids which characterize the electric current. If in a homogeneous conductor no effect is observed, it is because the two currents produced on each side of the heated point are equal and in contrary directions; but a difference of structure modifies the intensity of one of the currents, and the galvanometer shows the resultant produced from the two effects.

When the soldered joint of two different metals is operated upon, the direction of the current depends upon the nature of the metals associated, and it is impossible to give any precise rule upon this point. In the following list, the result of experiments made by Becquerel, the current traverses the heated joint, proceeding in consecutive order through the metals:—bismuth, platinum, lead, tin, copper, silver, zinc, iron, antimony.

The *intensity* of thermo-electric currents also depends upon the nature of the metals joined together; and each of these associations has an electromotive force peculiar to itself, which has been called *thermo-electric power*.

595.




For the purpose of comparing these thermo-electric powers, Becquerel made use of a chain, A, B, C, D, E, F, G, Fig. 595, formed of several metals soldered successively one upon the end of the other. The ends of the chain being attached to a galvanometer, one of the joints was heated at a fixed temperature, 40° for instance, whilst the other joints were kept at zero.

The current produced having in each case to traverse a circle of equal resistance, its intensity may be considered as the proportional measure of the thermo-electric power of the joint, at least, from the temperature from which we operate.

It was in this manner that Becquerel obtained the following Table:—

| | | | |
|---|---|---|---|
| Iron—Platinum | 36·07 | Copper—Platinum | 8·55 |
| Iron—Tin | 31·24 | Copper—Tin | 3·50 |
| Iron—Copper | 27·96 | Copper—Silver | 2·00 |
| Iron—Silver | 26·20 | Zinc—Copper | 1·00 |

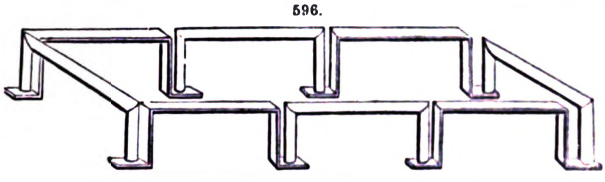
In these experiments Becquerel has proved the following fact, which is of real importance.

Supposing a joint of iron and copper to be heated, we shall have a current of a certain intensity; if between the iron and copper a piece of metal is interposed, or a chain of several metals of which we heat the two end joints, we shall have exactly the same results. This is a proof that the current is really due to the difference in the propagation of heat in the metals, and not, for instance, to contact.

The intensity of the current produced by a thermo-electric couple depends on the difference of temperature of two combined joints; and, within certain limits which are variable, as well as according to the metals employed, it is sensibly proportional; but after a certain time the increase in the intensity of the current abates very considerably. Thus for a couple of iron and copper it is scarcely sensible at 300°; beyond this the intensity of the current diminishes, becomes null, and ends by changing its direction. It should be noticed that the difference of temperature is not the *only* influence on this phenomenon—the absolute temperature must also be taken into account. Thus the current has not the same intensity, one of the joints being zero and the other 20°, as if the temperatures had been at 100° and 120°.

By joining together a number of thermo-electric couples and heating simultaneously the equal joints, we obtain a Thermo-electric battery. Fig. 596 represents an apparatus of this kind invented by Pouillet. It is composed of cylinders of bismuth bent at their extremities, and connected one with the other by means of plates of copper, also bent and soldered to the bismuth. If we plunge every second joint into any cold body—melting ice, for instance—whilst the remaining joints are heated at a fixed temperature, the battery produces a current which can be collected on a conducting-wire as in an ordinary battery.

596.

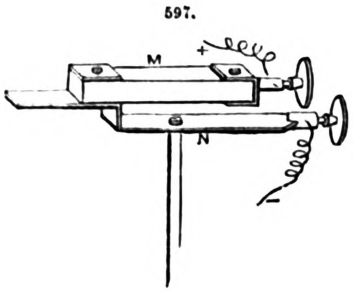


Viewed as agents for the production of the electric current, thermo-electric batteries have not as yet given very useful results as thermo-electric currents weaken rapidly, in circuits where there

is little resistance, through the conductibility of the mediums in which they are generated. Thus 120 couples at least of iron and platinum are necessary to produce an appreciable decomposition of water.

Edmond Becquerel has recently introduced, however, a thermo-electric couple of exceptional power: it is formed by connecting a plate of German silver N, Fig. 597, and artificial sulphate of copper M, the positive pole corresponding to the sulphate of copper.

597.

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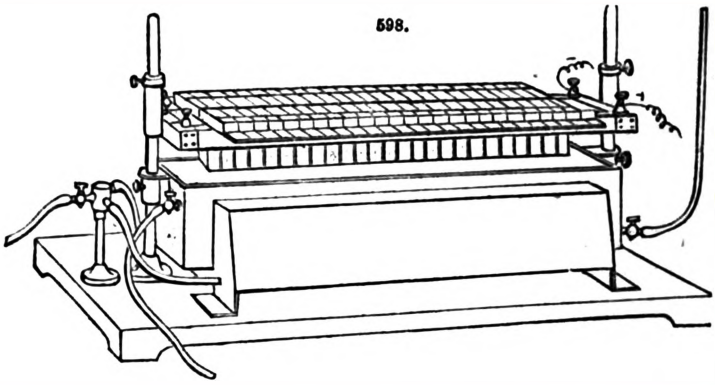
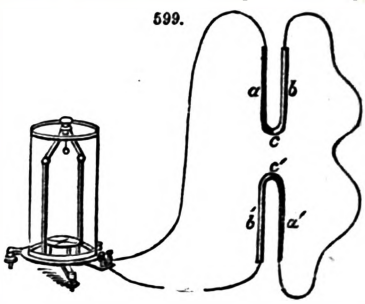


Fig. 598 shows a battery constructed upon this plan. The temperature of the joints is raised by means of common gas; and with thirty or forty elements it is capable of sensibly decomposing water, of maintaining an electro-magnet with a long coil, and of working a telegraphic apparatus.

Until lately, thermo-electric currents have only been made use of to measure temperatures under special conditions. The thermo-electric tongs invented by Peltier are, however, useful for indicating the temperature of any limited space. They consist of two thermo-electric couples, Fig. 599, of bismuth and of antimony, *a b* and *a′ b′*; the bismuth of one element being united by a wire to the antimony of the other, and the circle completed by a galvanometer. It results from this arrangement that if the space comprised between the two joints *c* and *c′* becomes at all warm, a current from the bismuth to the antimony will be produced in the two couples. These two currents act, besides, upon the magnet in the same direction; and as the bulk of the instrument is small, and its calorific capacity feeble, its sensibility is very great.

599.




It is with a species of very fine thermo-electric plummet that physicists are able, in certain cases, to penetrate without injury those organs which they wish to have access to in order to study the temperature of organized beings, as to the variations experienced under particular circumstances.

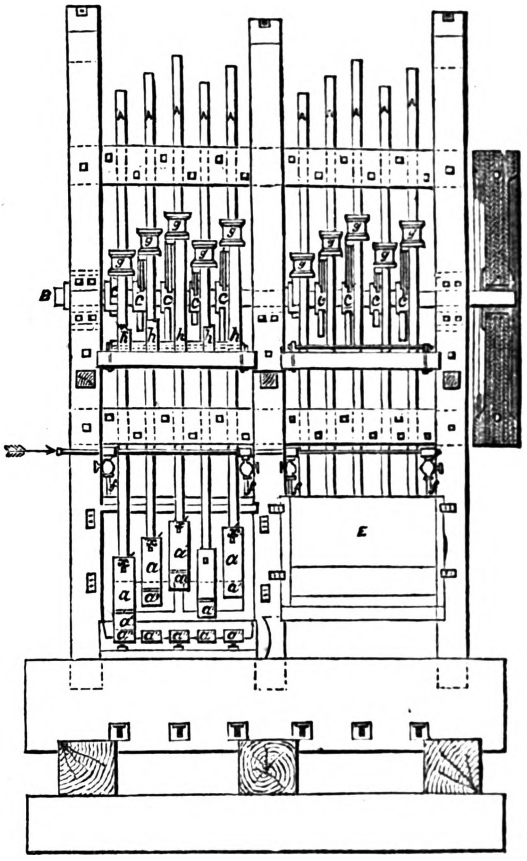
We conclude by mentioning the apparatus employed by Becquerel to measure the temperature of the air. It consists of two thermo-electric tongs, one being placed out of doors and the other in the laboratory. A galvanometer placed in the circuit indicates zero when the two tongs are at the same temperature. It is sufficient, then, when the needle is deflected, to heat or refrigerate the second tongs in such a manner as to bring it back to zero, to tell the temperature of the air. See Boring and Blasting. Telegraphy.

BATTERY, employed to crush auriferous rock. Fr., *Moulin à pilon*; Ger., *Stampfmühle*. The stamping mill or battery consists of a series of heavy pestles working in a rectangular mortar, each of which is alternately lifted by means of a *cam*, and subsequently let fall with its full weight upon the ore to be operated on, and of which, after being previously reduced to fragments of proper dimensions, a constant supply is introduced into the mortar, or battery-box.

When quartz-mining was first practised in California, the lifters or stems of the pestles employed were made of wood, furnished with cast-iron heads, attached by means of a wrought-iron shank driven into the lifter, and secured by two strong rectangular bands of flat iron. In most mining districts in which these wooden stems are used, the lifting of the pestle is effected by a large wooden or cast-iron drum, around the periphery of which cams are arranged in a spiral form, which, coming in contact with tongues, or tappets, fixed in the lifters, they are raised to a certain height, and, being suddenly released by the continuous motion of the axle, fall with their whole weight on whatever may happen to be beneath them. In California, however, another arrangement is employed for imparting motion to the pestles or stampers of a battery with wooden stems. Instead of a large cylindrical axle, a wrought-iron shaft is made use of, and on this are keyed a series of long curved cams, which enter mortice or slot holes, in the several stems, and cause them to be alternately lifted and released, precisely as in the case of the ordinary stamping-mill, provided with tappets and a drum-axle. When wooden stems are made use of, they are usually about six inches square, and cut out of ash, or some other hard wood, having a straight grain. These wooden stems with square heads have, however, been almost universally superseded by the rotary stamp, with a round stem of iron, to which a circular motion is given by the friction of the cam in lifting, and which, being continued up to the moment of its release, is prolonged during its descent, thus imparting a grinding action to the cylindrical head at the moment of its coming in contact with the rock to be broken.

The rotary stamp is said to be more efficient than the rectangular one, and to grind a larger quantity of rock in a given time; but however this may be, it is certain that the faces of the heads wear more evenly, and that a rotating battery requires less frequent repairs, than one made on the old principle. The battery-box is generally composed of one solid casting, and usually receives either four or five stampers; when additional reducing power is required, other similar boxes are placed on the same line. In most instances such batteries are arranged in sets of five stampers in each mortar, two of which are placed side by side in the same framing, ten stampers being thus set in motion by one shaft. Two five-stamp batteries, of a construction frequently employed, are represented, Fig. 600 being a back elevation, and Fig. 601 a transverse section; the iron rods A are the stamp stems, B the shaft, and C the cams. This shaft is provided at one end with a large pulley D, which is generally constructed of either kiln-dried wood on arms, inserted in a cast-iron boss, and then turned off in place, or is built solid of well-seasoned planks on a bored boss, and, as in the other case, turned, after being keyed to the shaft. When several of these batteries are arranged in one house, the motive power is communicated, by means of a broad belt, to the intermediate shaft B′, which is fitted with pulleys corresponding to those on the shafts B, with which they are severally connected by belts. These belts, which are manufactured out of a combination of canvas and india-rubber, are, from the first motion to the intermediate shaft, sometimes as much as 2 ft. in width. The belts from the second motion to the shaft on which the cams are keyed, are made of a thinner material, and are from 1 ft. to 14 in. wide. The lift of the stampers varies from 9 to 12 in., but 10 in. may be considered as about the average; and their weight, including the iron stem, varies from 550 to 900 lbs. The order in which the several stampers, included in one box, strike their blows, in a five-stamp battery, is not always the same in all establishments, but in most instances the first blow is struck by the central stamp. This is followed by the outside one to the right, then by the second to the left, afterwards by the second to the right, and finally by the stamper on the extreme left of the series. The number of blows struck by each stamper is from sixty to eighty per minute. The first portion of the stamper *a* is sometimes cast on to the stem, but more frequently it is fastened by wedges, and has a round aperture, in which is inserted the spill of the shoe *a′* firmly driven in or fastened by dry wooden wedges, which expand on coming in contact with water, and hold it securely in its place. The battery-box is either of iron, cast in one piece, or its bottom alone may be of cast iron, and its sides of wood; in which case the lower portion of it, together with the inside of the feed-hopper, must be lined with sheet iron, ½ in. in thickness, fastened by ⅝th bolts. Immediately under each of the stampers is placed a short cylinder of cast iron *a″*, which is retained in its position, either by fitting into a circular bedding, in which it may be keyed by wooden wedges, or it is provided with a square flange, which, coming in contact with those of the other dies and the sides of the box, act as distance-pieces, by which it is kept in its proper position. These, and the shoes of the stampers, are, when worn out, readily replaced by new, a considerable economy of time and money being the result; the parts worn out are merely coarse castings of chilled iron, without any kind of fitting. The hole *x* is for the purpose of forcing in a drift above the spill of the shoe, and thus removing it when a new one is required, whilst the hole *x′* is employed in the same way for getting off the boss from the stem. In Grass Valley, and some of the other more important mining districts, the boxes E are, almost without exception, composed of single iron castings; but in localities where amalgamation is conducted in the battery itself, the sides and ends are sometimes of wood, the bed alone being made of iron; and when this method of construction is adopted, two plates of amalgamated copper, ⅛th of an inch in thickness, are often bolted at *b* on either side of the row of stampers. The rock to be crushed is introduced by a shovel at *c*, and a plate of perforated sheet iron, fastened either in a wooden frame, or retained in its place between the two rectangular iron bands, tightened by cotters, is introduced before the opening *d*. The battery-bed, whether entirely of iron, or consisting only of an iron bottom, with lined wooden sides, is firmly bolted to a block of wood, at least 2 ft. square, and of which the dimensions, when very heavy stampers are employed, are even much greater. This either forms, as in the drawing,

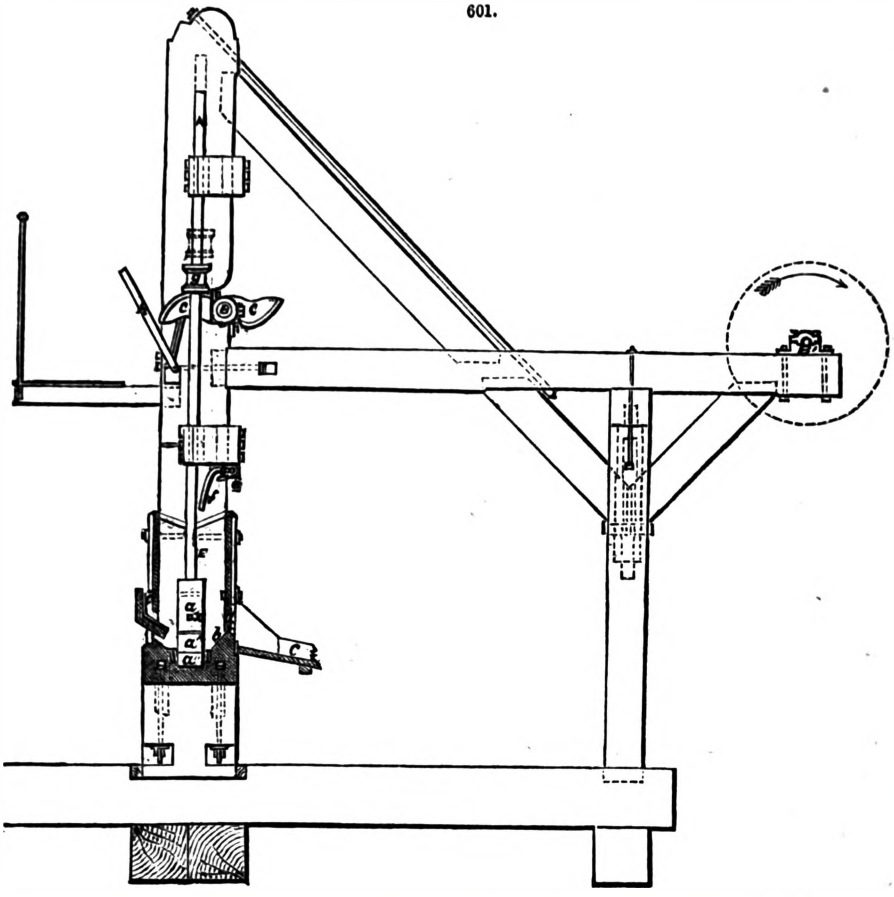
600




T

a portion of the general framing of the arrangement, or is now more frequently, to prevent jarring, made quite independent of it. It is, however, essential that this portion of the structure should be well bedded on a solid foundation, and, if possible, rest directly on the bed rock. Occasionally

601.



*Reference.*—*A*, Stamp lifters or stems. *a*, Stamp-heads. *a'*, Stamp-shoes. *a''*, Stamp-dies. *B*, Cam-shaft. *B'*, Second-motion shaft. *b*, Amalgamated copper plates. *C*, Cams. *c*, Feed-hopper. *D*, Driving-pulley. *d*, Grating. *E*, Battery boxes or coffers. *e*, *f*, Water-pipes. *G*, Blanket-board. *g*, Bosses by which stampers are lifted. *h*, Props for stampers. *x*, *x'*, Drift-holes.

quartz is crushed dry, but much more frequently water is admitted, and for this purpose a gas-pipe *e* affords the necessary supply, which enters the boxes through the branch pipes *f*, fitted with cocks for regulating the quantity introduced. The studs *g*, against which the cams come in contact, and by which the stampers are raised, are fitted on the iron stems by means of keys, which admit of their positions being readily shifted, when rendered necessary by the wearing of the shoes.

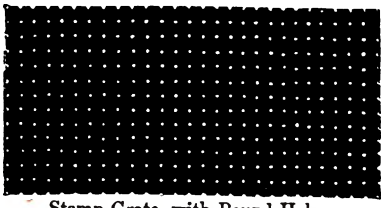
The props *h* shown in one of the batteries, but omitted in the other to avoid complication, are used for keeping up the stampers, either when the battery-box is being cleaned, or when a portion of the machinery is thrown out of action for the purpose of repair; to do this they are successively pushed forward, so as to catch beneath the several bosses *g*, when lifted by the cams to their full height. When not so employed, the props are allowed to fall back out of the way of the stems, as shown in the sectional drawing. The size of the apertures in the gratings or sieves at *d*, differ in accordance with the fineness of the gold contained in the rock treated, and is also, to a certain extent, varied in conformity with the particular views of the superintendent of the mill on that subject; but it is evident that with very small apertures the amount of quartz crushed, all other conditions being equal, will be less considerable than when a coarse screen is employed. The size of grating commonly made use of in some of the best mills in the Grass Valley district is shown, Fig. 602, which is known as No. 8.

In order to combine strength with the largest possible open surface, the apertures are sometimes made of an oblong form, and arranged as in Fig. 603.

In some establishments these gratings are fixed perpendicularly, as seen in Figs. 600, 601; but more generally they are slightly inclined outward, and this arrangement is evidently attended with certain advantages. When the grating is placed perpendicularly, a particle of quartz or other pulverized matter, splashed against the screen by the fall of the stampers, can only pass through it in case of being projected directly through one of the openings; and should it strike against a portion of the solid plate between the holes, will run down with the water on the inside,

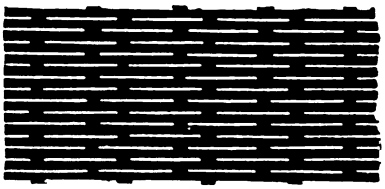
and again settle in the battery-box. If, on the contrary, the grating be placed at a considerable inclination outward, a particle of pulverized rock, which has not been projected immediately through the grate, may, on running back with the water over its inner surface, pass through one of the apertures and escape into the trough on the outside of the battery.

602.



Stamp Grate, with Round Holes.
(Full Size of Apertures.)

603.

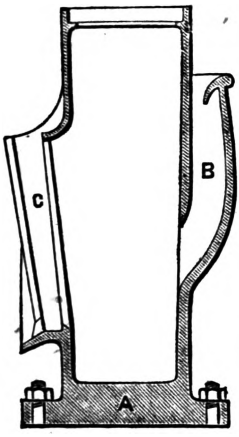


Stamp Grate, with Oblong Holes.
(Full Size of Apertures.)

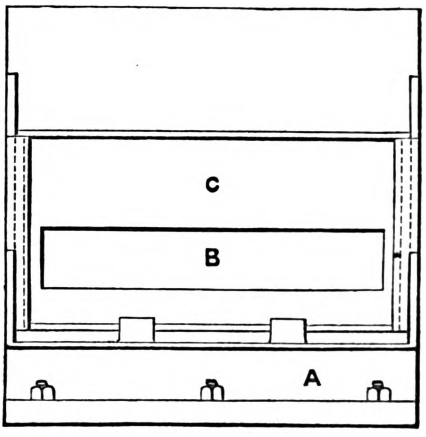
In all machines of this description, it is of importance that each particle of the rock operated upon should escape from the action of the stampers as soon as it has become sufficiently reduced in size, and with this view the grate-surface is in the Californian mills extended as much as possible, being generally made of nearly the full length of the battery-box. With a view of supporting the grating, and protecting it against injury from the impact of the water dashed against it by the falling stampers, the sheet-iron plate is externally strengthened by the application against it of some thin iron bars.

When the high cast-iron mortar is made use of, which is now generally the case, it has the form represented, Figs. 604 and 605, which the first is a transverse section, and the second a front elevation; the dies are fitted on the bottom A, and the quartz fed through the opening B, whilst the screens are fastened, by nails or screws, to a frame which is firmly secured in grooves provided for its reception at the ends of the mortar, and by two lugs at the bottom of the opening C.

604.

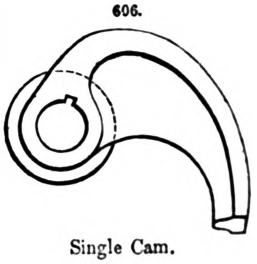



605.




Iron Battery-box.

606.



Single Cam.

In some cases, instead of employing a double cam, as seen in Fig. 601, a single one is made use of. This has generally the form shown, Fig. 606, and possesses the advantage of allowing the axle to be placed nearer the stamp stem than it can with any other cam, and also that by its use a greater number of blows can be struck per minute without danger of breakage.

The auriferous material having been reduced to the state of a finely-divided powder, it becomes necessary to provide means for the concentration and separation of the gold, which is more or less perfectly effected by an almost infinite number of different contrivances, varying slightly in their details in almost every establishment that may be visited. However much the processes employed may differ in this respect, only two decidedly distinct systems are now practically in use in California, namely, amalgamation in the battery, and crushing without the use of mercury, amalgamation being subsequently effected by means of appliances specially designed for that purpose.

*Amalgamation in the Battery.*—When this method is adopted, the batteries are often provided with amalgamated copper plates *b*, Fig. 601, about 5 in. in width, extending the whole length of the box; one on the feed side and the other at the discharge, the latter being protected by the sheet-iron lining of the feed-hopper, and each having an inclination of from 40° to 45° towards the stampers.

When these are not employed, spaces for the accumulation of amalgam are allowed between the dies and the sides of the box, and vertical iron bars are placed inside the gratings, between which the hard amalgam is found to collect. The copper plates are covered with mercury, by means of a rag dipped in dilute nitric acid, with which quicksilver is rubbed over the surfaces to be coated, in the same way as on those used in ordinary sluices. Quicksilver is also sprinkled into the boxes, by the feeder, at intervals of about an hour, and in quantities varying with the richness of the rock operated on. One ounce of gold requires for its collection about an ounce of mercury;

but when the gold is in a finely-divided state, the addition of another quarter of an ounce of this metal is thought advantageous. The proper proportion is, however, readily ascertained by closely watching the discharge. If any particles of amalgam which may pass through be hard and dry, a little more quicksilver must be introduced; but if, on the contrary, they be soft and pasty, or globules of mercury make their appearance, the supply in the battery must be diminished.

When the proportion of mercury has been properly adjusted, the amalgamation of the gold is very completely effected, except in cases in which the ores contain large quantities of lead or antimony, and have been previously burned for the purpose of expelling their more volatile constituents, by which treatment the particles of gold often become coated in such a way as to interfere with their combination with mercury. When the proper proportion of quicksilver has been regularly introduced, and the rock contains coarse gold, from 60 to 80 per cent. of the gold saved is caught in the battery; but when, as in the case of some of the ores of Nevada, the gold is in a very finely-divided state, and is associated with ores of silver and other sulphides, the results obtained are less satisfactory. The alloy resulting from the treatment of such ores contains silver, and in some cases affords from 300 to 400 thousandths only of gold, often producing a spongy amalgam of a dark colour, made up of an aggregation of numerous finely-divided particles. Küstel is of opinion that this effect is partially due to the presence of manganese, but it appears difficult to understand how this substance should influence, to any important extent, the combination of gold and mercury. This amalgam is exceedingly light, and is, therefore, difficult to collect, either by riffles, copper plates, blankets, or any of the other appliances commonly employed for the purpose.

When, therefore, ores contain much lead or antimony, amalgamation in the battery is not to be recommended, since this spongy amalgam is more difficult to retain than the most finely-divided gold, and a large proportion of it floats off over the blankets, riffles, or copper plates, which may be arranged for the purpose of arresting its progress. There is, besides, no evidence that battery amalgamation possesses, under any circumstances, a decided advantage—for gold ores not associated with sulphide of silver—over stamping without the use of mercury, and in some of the most productive gold districts it is seldom resorted to.

In order to collect the particles of gold and amalgam escaping from the battery-box, various ingenious contrivances are employed; but as these arrangements differ but little in their details, whether mercury be employed in the battery, or the amalgamation entirely effected after the escape of the pulverized material through the screens, we will proceed to describe the system generally in use in the northern quartz mines, in which the various arrangements are of the most improved description.

This article, with some slight alterations being made, is taken from J. A. Phillips' excellent work, 'The Mining and Metallurgy of Gold and Silver.'

BATTERY, Ship's. Fr., *Batterie flottante;* Ger., *Schwimmende Batterie;* Ital., *Batteria galleggiante;* Span., *Bateria.*

Any place where cannon or mortars are mounted, for attacking an enemy or for battering a fortification, is termed a battery. This term also signifies a body of cannon for use, taken collectively; as, to discharge the whole battery at once; a ship's battery.

Cannon were introduced on board ships soon after these weapons came into general use, and they were at first applied on the non-recoil system in wooden immovable carriages; but as the size increased, it was found indispensable to allow of, but to absorb, the recoil, and to provide means of training or pointing the gun irrespective of the movements of the ship. Thus the trunnions of the gun for elevation and depression when the level was changed by the "heel" or inclination of the ship, the "trucks" or wheels on which the carriage and gun moved backwards when fired or were run "up" or "out" when loaded after firing, became necessary fittings. Then there was added, still further to meet more onerous conditions, "breechin" ropes to limit the recoil, and tackles to run the gun out. The battery was that part of the ship where the heaviest artillery was carried; smaller pieces were distributed about the poop and forecastle; and the ship was divided into two strong sections, called close quarters, forward and aft, where, in the event of boarding being successful, the crew could retire and fight, as in a castle or tower, although the enemy occupied fully the midship deck.

Modern science has recognized two broad divisions of the battery—broadside and turreted guns. In the turret system a few guns of great power are carried in the centre line of the ship, and are so fitted as to command a fire all round, where there are, as in a raft, no impediments from masts, ropes, or sails, and not much lateral motion, as pitching or rolling.

Cowper Coles, in Europe, and J. Ericsson, in America, are the chief exponents of this system. There is a subdivision of turrets into fixed and revolving. The fixed turret approaches nearly to the box-battery; the revolving turret approaches most to the single pivot-gun. Examples of each are given. See Ordnance. With a given tonnage, more guns of equal power can be carried on the broadside than on the turret system, since that necessitates two separate armours—the one for the gun, the other for the ship; and it is not a sufficient answer that less of the ship's side has to be armoured, and therefore less weight need be carried; since, if the same number of guns only are insisted on, no more armour is necessary in the one case than the other. In the latest development of the two principles, from twelve to sixteen guns of equal weight and power can be carried in the broadside-ship, as against four to six in the turret, on the same tonnage and at the same expense. Added to this, there is the fact that no turret-ship has yet been devised that was equal as a habitation for seamen, and therefore, in seaworthy qualities, to the broadside-ships. For coast and river defence the turret ships or rafts are eminently useful; for keeping the sea in all weathers they are utterly inefficient.

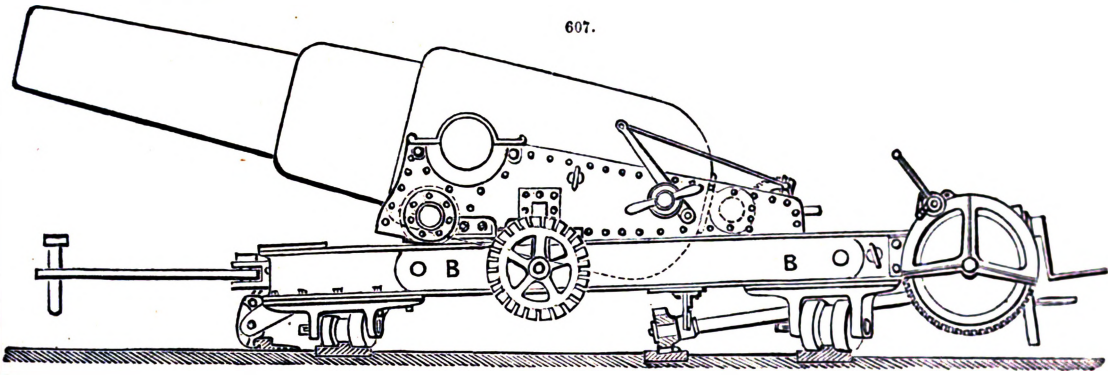
The forms of carriage for the batteries of ships have undergone a considerable change within a few years, mainly consequent on the introduction of much heavier pieces of ordnance up to 20 tons, where previously 5-ton guns were the exception, and the fact that armour outside the ship renders

it possible to apply more complicated and delicate mechanism without the fear of having it too much exposed to the effects of shot and shell.

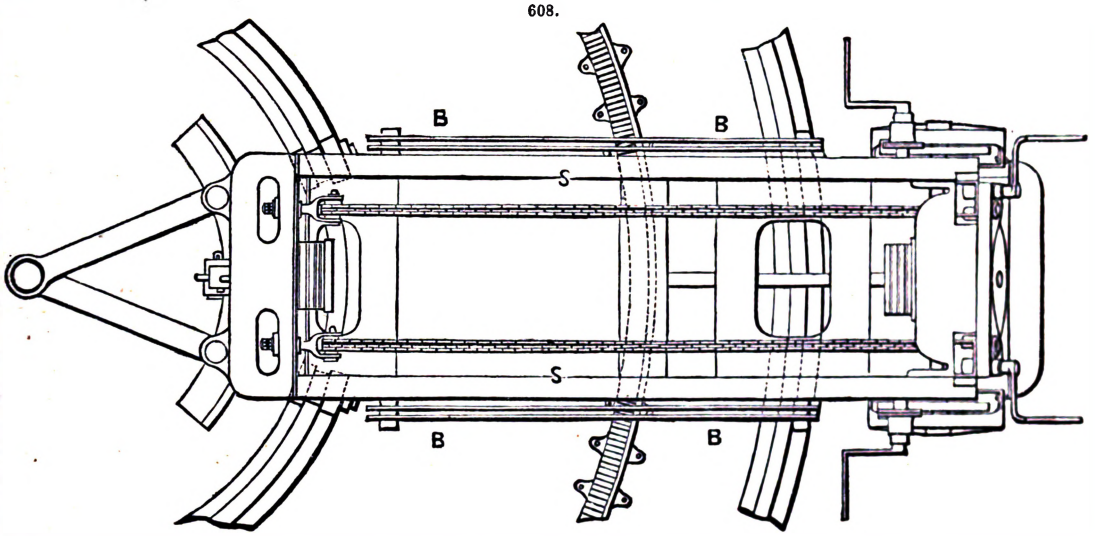
Simple as the invention of a suitable gun-carriage for heavy naval ordnance may appear, yet, in attempting this apparently easy task, before R. A. Scott succeeded in accomplishing it, many ingenious inventors failed. Captain Scott found that it was of much importance to keep heavy guns as close down to the deck as possible, to give more effect to his compressors, and not, as Scott and others suppose, that the shock is greatly diminished by the deck by having the gun so placed. The principles upon which the compressors are constructed, and those by which they are operated, were first brought into practical operation by J. Ericsson (see GUN-CARRIAGE). However, at present it is only necessary for us to show the value of Scott's gun-carriage in the formation of a ship's battery.

Fig. 607 is an elevation, and Fig. 608 is a deck-plan, of one of those carriages, constructed for one of the 10-in. broadside-guns of H.M.S. 'Hercules.' The carriage first proposed by Scott, which we gave in our specimen Part, differs in arrangement, but not in principle, from the carriage shown in Figs. 607, 608.

607.




608.




The sides S, S, Fig. 608, of the slides are of -section iron, a portion of which is hollow, and sometimes filled in with wood, which projects slightly beyond the top and bottom flanges. On the outside of the slide on each side there are supported by pins a pair of iron bars B, B, Figs. 607, 608; these bars are placed at a short distance apart, and grasped by the compressors at the same time as the sides of the slides are grasped: the parts secured by the compressors are shown in section, Fig. 609.

609.

Although Scott has succeeded in effecting the object he had in view, yet it does not appear that he is aware that he, or rather Ericsson, has introduced a mechanical principle entirely new, upon which shocks and concussions may be given without returning any great amount of rebound. Each part of his invention shows much practical skill and ingenuity; yet the whole would fail but for the symmetrical and uniform grips taken by his compressors. In fact, he can secure composite beams of wood or iron so that their vibrations become as regular as the strings of a violin: the concussions of the vibrating waves of the compound beams B S B destroy a force which in other cases produce rebounds. The friction of which Scott speaks has not the effect which he attributes to it. If the beams B S B were made of iron, they would not answer the purpose as well as wood: the wood receives all the force, and passes it forward. Wood does not offer a greater resistance

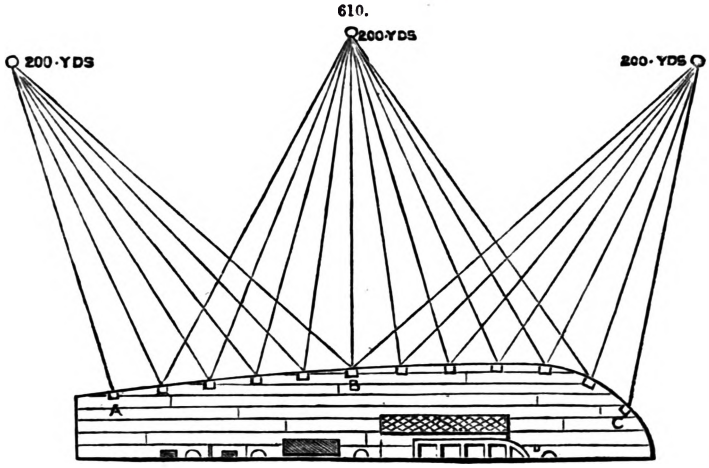
than iron, but the wood passes the force applied over the parts equally; whereas the iron passes the force with a rebound or shock. The one receives it, and, to use an ordinary phrase, swallows it, and passes it more leisurely to other parts; iron would receive the force, and return it suddenly, which might cause mischief.

It should not be forgotten that a vessel of 30 tons can easily carry, and may with impunity make use of, a gun of 5 tons weight, since the vessel in such a case becomes the gun-carriage floating in water, and capable of absorbing the recoil, as a larger vessel will not do. The 'Staunch' is an example of this class of gunboat, and in her the gun, when not in use, is lowered, so as not unnecessarily to keep the centre of gravity high when not fighting. Any modification of the Moncrieff principle applied to gunboats or even vessels of larger size, would supersede turrets by the adoption of this alternate raising and lowering of the gun itself, since no armour is needed for the protection of the gun during its short exposure in pointing and firing. The broadside battery has in no great degree changed since the system was first introduced, unless by the providing more and more efficient bow and stern fire, or, as it is called, *all-round fire*, by splaying the ports, by retiring them or placing them in indents (this system having the same objection as deep embrasures, in that the enemy's shot are guided into the ship), or again, and most successfully, by better means of training on axes or turn-tables, and by muzzle-pivoting. In great naval battles, the broadside has always a marked advantage, since no such action has been fought without a necessity for engaging on both sides; and here number of guns must tell, and the turret system, which admits of but few guns, must necessarily be at fault.

A battery is said to be concentrated when a certain number of the guns are so trained and laid, as that, on being simultaneously fired, their shot will strike at nearly the same moment in nearly the same spot at a previously determined range.

This is done by measuring the distances between the centres of each port; and, after deciding the desired range to be, say 200 yards, calculating each angle of training, and inserting a mark on the deck. Now, at this range there will be no elevation. Each gun is trained by the nail on the deck; and a good marksman being posted at the gun, on which the whole battery or a part of it is concentrated, all the guns are fired at his word of command, and their shot must inevitably strike wherever his does. As the range is a fixed quantity, and forms one side of the triangle; as the angle of training of the gun chosen to concentrate on is either 90° with the line of keel for the midship gun, or about 45° for a bow or stern gun; all the other intermediate angles are easily calculated from these by the diminution of base due to the distances between the centres of gun-ports. 800, 600, and 200 yards are the usual distances for concentration

610.



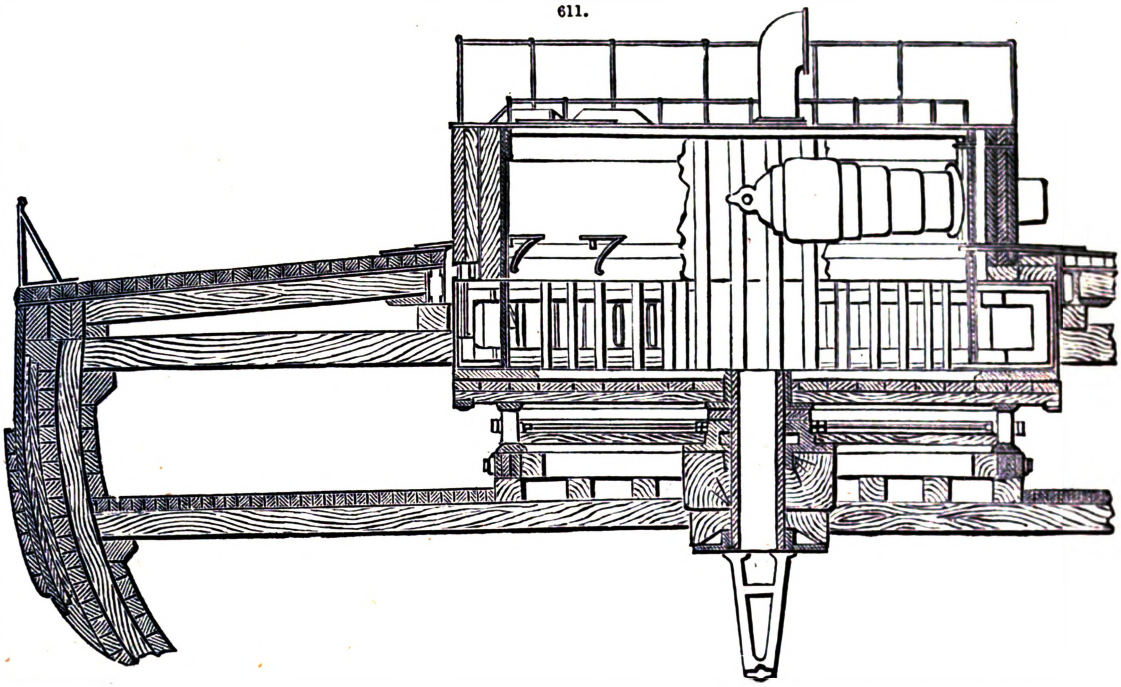

Guns concentrated on A, the after-gun; B, the midship; and C, the foremost gun.

The general arrangement and details adopted by Capt. Coles, R.N., in the construction of the cupola or turret batteries on board the 'Royal Sovereign' are shown in Figs. 611, 612.

The 'Royal Sovereign' carries four turrets, mounting in all five 300-lb. Armstrong guns, two in the forward and one in each of the after turrets. We take the forward or twin-gun turret, which is 22 ft. 9 in. in diameter, and 18 ft. 9 in. outside, Fig. 611. First, we have a massive framework of wood constructed on the main deck, and supported by the deck-beams and wrought-iron columns. The centre is formed of two large rectangular blocks of English oak, making a square of 6 ft. 3 in. × 2 ft. 6 in. deep, with a round hole in the centre 26 in. in diameter. Immediately under this is placed two balks of English oak, 18 in. × 15 in. × 30 ft. in length, running fore and aft, and bolted down to the deck-beams; on this, segments of English oak are placed, cut to an inner radius of 9 ft., and forming a ring of 9 ft. 6 in. outside diameter, which is firmly bolted to the fore-and-aft beams just mentioned; round the outside of this ring three bands of American oak are bent, each 12 in. deep × 3 in. in thickness, and bolted to the segment forming the inner ring by 1-in. bolts. Six arms or spokes radiating from the centre, each 18 in. × 12 in., like the centre and inner ring, are made of English oak; on this substantial and massive framework is bolted a turned cast-iron roller-path. In the centre is a hollow tube of wrought iron, 2 ft. 2 in. outside diameter, 3 in. in thickness, and 7 ft. 3 in. in length, forming the pivot on which the turret revolves, and acts as a safe communication with the magazine below. A large casting, which forms the centre, round which a live wrought-iron ring, lined with brass, revolves, is placed round

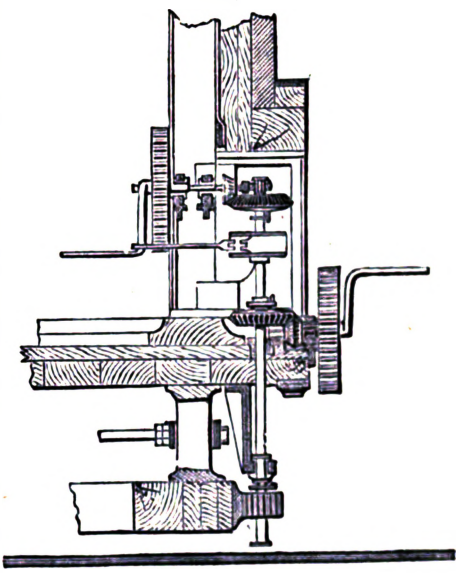
this pivot, and sits upon the wooden framework bolted through to a somewhat similar casting below, which is supported by a forked wrought-iron column resting on the keelson. We are now come to the turn-table or platform on which the turret is built. It is a large disc of woodwork, 24 ft. 8 in. in diameter, and 12 in. in thickness, built of oak slabs, 14 in. × 6 in., bolted together, the top layer being placed at right angles to the bottom one. Near the outside the thickness is

611.



increased 4 in. by a circle of oak, 3 ft. 9 in. in width × 6 in. in thickness, let into the other portion 2 in. On the under-side of this platform is fixed the cast-iron upper rolling-path, fastened by 1-in. bolts, which pass through the frame to rings of wrought iron, 9 in. × ¾ in., let into the top, to which they are secured by nuts. In the centre of this table is fixed a large kind of angle-iron ring of cast iron, with the flange on the bottom side, and bolted through in the same manner as the path. This casting is bored out, and a brass brush let in, ¾ in. in thickness × 15 in. in depth, which forms the moving rubber surface round the axes. Between this casting and the lower one are arranged twelve brass conical rollers, 5½ in. in diameter at their largest part, and 5½ in. wide, supporting the centre weight of the turret. These rollers are placed in a live ring of brass; the pins round which they revolve are 1¼ in. in diameter, and screwed into the inner part of the brass ring with a jamb-nut screwed up to prevent the pin turning. A ⅛-in. washer is then put on, and segments of wrought iron, 4 in. × ¾ in., are fastened over the whole thing by 1-in. square-headed wood screws; the outside nuts of the roller-pins are tightened against these segments. The centre line through the inner rollers is 5 in. above the centre line through the outer ones, which are thirty-six in number, made of cast iron and turned conical, the largest diameter being 18 in. × 9 in. wide; they are cast H sections, the boss is bored, and a brass brush fitted. The framework in which these wheels revolve is made of an inner and outer ring of wrought iron, each 6 in. × ¾ in. The inside diameter of the inner ring is 19 ft. 2 in., and the outside diameter of the outer ring is 21 ft. 3½ in. Like the outside ring of the centre rolling-frame, these rings are made in short segments with joint-plates on the inside, each fastened by four ¾-in. bolts, the two outside ones being long enough to pass through both rings, with a nut at either end; round these long bolts is a piece of 1½ in. gun-barrel tube, which acts as a stay or distance-piece, to which the rings are screwed home. There are thirty-six segments to each ring. The radius-rods are 2 in. in diameter,

612.



increased to 2¼ in. at the ends. The inner end is screwed into the live ring before described with a jamb-nut on the outside; the opposite end passes through the roller and large rings, with two jamb-nuts on the inside, and one nut, with a pin through it, on the outside.

On this turn-table is built the turret, a little eccentric to the platform, that is to say, the centre of the turret is 9 in. from the centre of the platform, and is formed of thirty upright frames, made of T-irons, angle-irons, and plates. The T-irons which form the inside circle are 6 in. × 10 in. × ½ in. The plates on the outside are 10 in. × ½ in., with an angle-iron riveted on either side, 3 in. × 3 in. × ½ in. The T-irons extend from the platform to the top of the turret, a height of 9 ft. 6 in., whereas the ½-in. plates and angle-irons only extend 3 ft. 7 in. in height, and are then brought round to form the support for the woodwork and armour-plating. Between the vertical T-irons, and beginning at 3 ft. 7 in. from the platform, are nicely-fitted balks of teak, 18 in. × 10 in. × 6 ft. in height; round this, and let in flush with the outside of the teak, are systems of diagonal bracing or trellis-work, with one hoop top and bottom, 6 in. × ¾ in., which is also the scantling of the diagonal bars. Over this is built another ring of teak balks, 18 in. × 10 in. × 6 ft., and on the outside of this is the armour-plating, consisting of twenty plates, 5 ft. 4 in. × 3 ft. 6 in. × 5½ in. in thickness, secured to the framework of wood and iron by four 2-in. countersunk galvanized bolts to each plate, passing through the inner lining, consisting of ½-in. plate-irons. In addition to this lining there are two wrought-iron rings in the inside, through which the bolts pass, and to which they are secured by an ordinary nut. The upper hoop is 14 in. deep × 2 in. in thickness, and the lower one 6 in. wide × ¾ in. in thickness. There is a double thickness of armour-plating, 12 ft. long, on the port-hole side of the turret, the inner plate being 4½ in. in thickness, making a total thickness of 10 in. solid plating. The roof is formed of wrought-iron rolled beams, something like a double-headed rail, except that the top flange is an inch wider than the bottom one, the top being 3¾ in., and the bottom 2¾ in. These beams are 4⅝ in. deep, weighing 15 lbs. to the foot-run, or 45 lbs. to the yard. They are placed 2 in. apart, and pass through the woodwork resting on the armour-plates; these are covered with 1-in. wrought-iron plates, bolted to them. There are also side-laps about every 3 ft., which are bolted to the armour-plates. There is an opening above each gun, 20 in. in diameter and 9 in. deep, packed round with wood, covered with plating; these are merely light-holes. There are also two slits over each gun, 4 ft. long by about 8 in. wide, for the "captain" of the gun to take his aim through. There are two cowl-pipes for ventilating each turret. The short standards with hand-rails are used for stowing the hammocks in, while the long ones merely serve as a hand-rail for the look-out. The port-holes are 20 in. × 3 ft., half round top and bottom, and lined in the inside with iron, ¾ in. in thickness.

We now come to the turning-gear, which consist of four winch-handles and gearing, working two vertical shafts, one on each side of the cupola, 2½ in. in diameter. Two of these handles work inside the turret, the other two on the outside. As they are all four alike, we need describe only one, which consists of a common winch-handle, Fig. 612, 15 in. radius, attached to a spur-pinion, 10 in. in diameter, 1½ in. pitch of teeth, 3¾ in. breadth of same, twenty-one in number. This pinion works into a spur-wheel, 30·4 in. in diameter, 1½ in. pitch of teeth, 3¾ in. breadth of same, sixty-three in number. To this is attached a bevil-pinion, 6 in. × 1¾ in. × 4 in. × 11 teeth, working into a bevil-wheel, 18 in. × 1¾ in. × 4 in. × 33 teeth. This wheel gives motion to the upright shaft, to the end of which is fixed a spur-pinion, 10 in. × 2¼ in. × 6 in. × 14 teeth, working into the large wheel bolted to the framework, the size of which is 22 ft. × 2¼ in. × 6 in. × 371 teeth.

The mechanical advantages gained by the gearing up to the periphery of the pinion which works into the rack = 27 to 1.

If we suppose the whole weight of the cupola and guns, 140 tons, to be concentrated on a circle of 15 ft. in diameter, we have: $\frac{30 \times 30{\cdot}4 \times 18 \times 264}{10 \times 6 \times 10 \times 180} = 40{\cdot}1$ to 1.

Eight men are the full complement for working the gearing, four inside and four outside the turret, the speed = 1 revolution a minute. Four men can work it, but, of course, they take double the time.

In addition to the four winches just described, there is what is termed the deck turning-gear, consisting of two winch-handles, each 15 in. radius, working a bevil-pinion 11·1 in. × 1¾ in. × 5 in. × 20 teeth, working into a bevil-wheel, 32·25 in. × 1¾ in. × 5 in. × 58 teeth. At the other end of the shaft to which this wheel is attached is a face-pinion, 10 in. × 2¼ × 6 in. × 14 teeth, working into face-rack on turret, 24 ft. 6 in. × 2¼ in. × 6 in. × 412 teeth, the mechanical advantage gained by this gearing from the winch-handle up to the periphery of the pinion which works into the rack = 8·7 to 1. But assuming, as before, that the weight is concentrated in a circle 15 ft. diameter, we have—

$$\frac{30 \times 32{\cdot}25 \times 294}{11{\cdot}1 \times 10 \times 180} = 14{\cdot}2 \text{ to } 1.$$

There are three small crab-winches attached to the revolving platform, two of which are used for working the guns, and one for lifting the shot.

There is a clear space of 3 in. all round the turret and the well or hole in the deck, and this space is covered by a leather flap or ring attached to the turret, and bearing on a brass ring fixed upon the deck; this leather flap is weighted with a strip of iron round the outside, in order that it may fit close to the deck.

The edge of the hole in the deck, within which the turret is placed, is strengthened by a wrought-iron well-ring, weighing about 1½ ton, and formed of 1-in. plate of wrought-iron, 2 ft. deep, with angle-irons on the outside, top and bottom. From this ring radiate iron beams, some leading transversely to the sides of the vessel, and the others to the deck-beams, to which they are firmly attached. On these beams are laid the 1-in. plates forming the deck, and upon these is placed around the turret a "glacis-plate," consisting of a ring 30 in. wide, and tapering in thickness from 3 in. at the inner to nothing at its outer edge.

Over the glacis-plate comes the deck, tapering in the opposite direction from 6 in. to nothing,

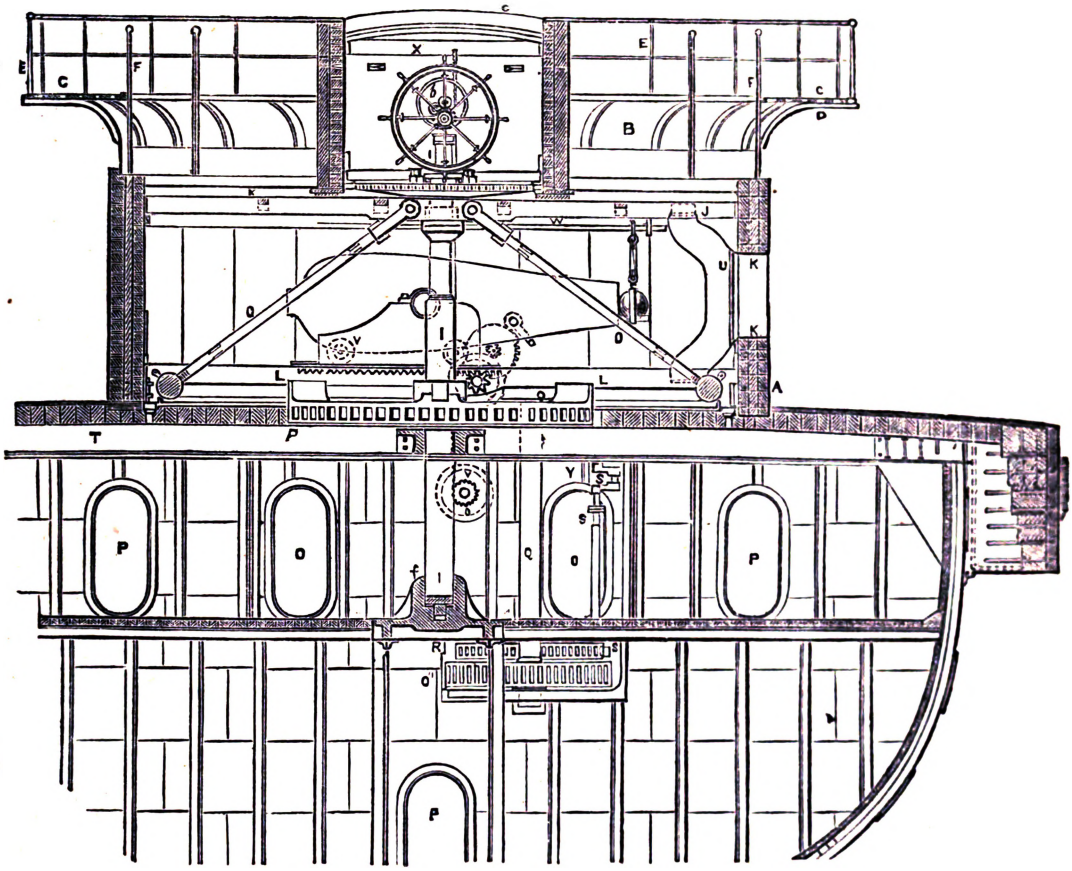
and upon this is laid round the turret a ring of $\frac{3}{8}$-in. stamped wrought-iron plates, 2 ft. 6 in. wide, which serves to protect the deck from being scorched by the discharge of the gun.

The deck of the vessel rises at an angle of 5° from the sides towards the centre, and is formed of 1-in. wrought-iron plates, covered down the centre for a width of 26 ft. with 8-in. teak planking; the remainder of the surface is covered with 6-in. planking. The deck is carried by wrought-iron rolled beams placed 12 in. apart between the main wooden deck-beams, and the 1-in. plating is laid on in strips about 12 ft. long by 2 ft. 6 in. wide, joined together by $\frac{3}{4}$-in. rivets, and covering strips 4 in. × 1 in. The 1-in. plating is doubled round the openings for the turrets, hatchways, and funnel; and a double thickness is also carried, fore and aft, between the turrets and the sides of the ship. The armour-plates are bedded upon crossed diagonal planking, which was added to the original sides of the vessel on her conversion from a three-decker, making the total thickness of the timber-backing 3 ft., as shown in Fig. 611.

It may be necessary to add that the turrets are now made concentric in place of eccentric to the platform; that, in lieu of the small winches before mentioned, they put a much larger one, with an endless chain, to work the guns. See a paper by J. Baily, published in the 'Artizan,' 1868.

The ship turret-battery of Ericsson is shown in Fig. 613; the pilot-house is stationary and above the rotating turret; this arrangement enables the commander to direct the helmsman, who

613.




is near him, and the gunner below, while he, the commander, is observing the enemy. The turret A is 24 ft. inside diameter, 9 ft. 6 in. high, and 15 in. thick, composed of two separate cylinders formed of plates 1 in. thick, lapped and riveted together. The outer cylinder, composed of six plates, was built on a staging above the inner one of four plates, and after completion was slipped over it. The annular space of $5\frac{1}{4}$ in. between the cylinders is filled with segmental slabs, 5 in. thick, made of the best malleable iron. These slabs were made only $11\frac{1}{2}$ in. wide, in order to save time. B is an extension attached to the top of the turret, composed of plate $\frac{1}{2}$ in. thick, bent outward in the form of a trumpet, in order to throw off the sea in bad weather; C is a wooden grating extending round the turret extension, supported by and bolted to brackets D, at intervals of 3 ft.; E, stanchions for supporting a rope-rail carried round the wooden grating; F, stanchions for sustaining an awning in fine weather; G, the pilot-house, 8 ft. inside diameter, 7 ft. high, and 12 in. thick, formed of two separate cylinders, each composed of six plates 1 in. thick, lapped and riveted. After completion, the larger cylinder was forced over the smaller one. The roof is composed of three plates, 1 in. thick, covered with 8 in. thickness of wood, and an outer plating 1 in. thick. The roof is inserted below the top of the cylinders, and is thus protected from shot; both cylinders are pierced with eight elongated sight-holes. The weight of the pilot-house is supported by a broad

wrought-iron cross-piece H, secured to the circumference of the house by angle-irons, this cross-piece resting on a collar near the upper end of the stationary vertical pillar I, round which the turret turns. The floor of the pilot-house consists of wooden gratings provided with grated hatches moving on hinges. J is the upper turret-beam of wrought iron, 11 in. deep, 8 in. thick in the middle, sustaining rafters which support a series of bars K, 4 in. deep, 3 in. thick, placed 2½ in. apart, on the top of which are placed perforated plates 1 in. thick covering the entire turret. L, L, are the gun-slides, four in number, 10 in. deep by 4 in. thick, of wrought iron, the ends of which rest on plate-rings secured to the turret, their middle resting on the lower turret-beam M. N is a cross-piece of wrought iron, suspended under and let into the central pair of gun-slides, and into which are tapped the diagonal braces O. By means of these braces O, the entire weight of the turret may be suspended on the collar *n'* of the turret-shaft. P is a spur-wheel bolted to the under-side of the gun-slides and lower turret-beam, and worked by a pinion Q on the vertical shaft Q', at the lower end of which is the spur-wheel Q'', driven by a pinion on the axle R, and on which is fixed the spur-wheel R'. This spur-wheel is in turn worked by the pinion S, on the lower end of the shaft S', which is provided with a crank S'', and turned by an engine consisting of two cylinders 12 in. in diameter and 16 in. stroke, placed at right angles, and bolted to the under-side of the deck-beams T. U is a port-stopper for preventing shot from entering the turret, composed of a massive block of wrought iron bent in the form of a crank, provided with bearings, in which it may be turned into such a position as to admit of the gun being rolled out, while, when turned into another position, it closes the port. V is the gun-carriage; V' a rack on the under-side of the same; V'' a pinion for moving the gun on the slides, and by means of which, combined with a friction-coupling, the recoil is checked; W is a radial sliding-bar for passing the shot into the muzzle of the gun without handling; X is the steering-wheel, and Y the double barrel for the steering-chains Y', which run upon rollers under the deck-beams. *a* is a bar of steel, 2½ in. square, inserted in a groove formed on the port side of the turret-shaft, provided with cogs on the opposite sides, by raising or lowering which, by means of a train of wheels in the steering-box *b*, the chain-barrel is worked through the pinion *c*; *e*, fore and aft bulkheads to support the weight of the turret and turret-shaft, strengthened with angle-irons, 6 in. by 4½ in., placed 18 in. apart, upon which rests the cast-iron saddle *f*; *g*, a key for regulating the height of the turret-shaft, above and below which are plates *g'* and *g''* of composition metal to prevent cutting; *h* is a cast-iron bearing for giving lateral support to the turret-shaft, into both of which square keys are let in, to prevent the shaft from turning; *i* is a wrought-iron plate, polished on the top side, secured to the deck; a corresponding plate of composition metal, with a projection on the inside, being fitted under the base of the turret, with which it revolves. This composition plate does not extend under the outside cylinder of the turret, which is supported by being bolted to the base ring *k*, as shown in the engraving: underneath this part of the turret the space is filled with oakum or similar material. Scupper-holes *l* are provided for carrying off any water which may enter the turret between the base-plates in a sea-way. Plates *m* are riveted to the four inside courses for sustaining the upward pressure of the gun-slides when the diagonal braces are screwed up, composition rings *n* being fitted between the upper turret-beam and the collar *n'* of the turret-shaft, nearly the entire weight resting upon this ring when the turret-shaft is fully keyed up. Doors *o* in the upper transverse turret-bulkhead afford communication between the berth-deck and the turret-chamber, the doors *p* forming communication to the after-part of the ship, and doors *q* in the lower bulkheads to the boiler-room and coal-bunkers.

*Of the Power of Symmetrical Turret-fire*, taken from 'Text-book to the Turret and Tripod Systems of Ship's Battery,' Cowper P. Coles, from plans by E. Pellew Halsted. Figs. 614, 615.

Fig. 614 is a deck-plan for a 7-turret first-rate vessel of war; and Fig. 615 is a midship section of a 7-turret first-rate vessel of war.

*Mode of Armament.*—Seven turrets or cupolas, with two guns each, so arranged that—1, the fire of four guns can be delivered in line of keel ahead and astern; 2, the central turrets, and very largely the deck itself, are protected from all raking fire; 3, the deck can be swept fore and aft, to prevent possibility of boarding.

COMMAND OF TURRETS: DETAILS FOR REFERENCE TO FIG. 614.

| | *With both Guns.* | *Additional with Single Guns.* |
|---|---|---|
| 1. | From 85° abaft port beam, to 50° abaft starboard ditto = 315°, or 28 points. | 2° aft on port side; 6° on starboard ditto = 8°, or ⅓ of a point. |
| 2. | From 50° afore, to 61° abaft port beam = 111°. Then, from 2° on port side of keel forward, to 81° abaft starboard beam = 173°. Total 284°, or 25¼ points, nearly. | 6° forward, and 6° aft on both sides = 24°, or 2¼ points, nearly. |
| 3. | From 75° afore, to 71° abaft port beam = 146°. Then, from 60° afore, to 71° abaft starboard beam = 131°. Total 277°, or 24½ points, nearly. | 2° forward, and 6° aft on port side; and 7° forward, and 6° aft on starboard side = 21°, or 2 points, nearly. |
| 4. | From 71° afore, to 71° abaft port beam = 142°. Then, from 71° afore, to 71° abaft starboard beam = 142°. Total 284°, or 25¼ points, nearly. | 6° forward and aft on both sides = 24°, or 2¼ points, nearly. |

5.

From 71° afore, to 60° abaft port beam = 131°. Then, from 71° afore, to 75 abaft starboard beam = 146°. Total 277°, or 24¼ points, nearly.

6° forward, and 7° aft on port side; and 6° forward, and 2° aft on starboard side = 21°, or 2 points, nearly.

6.

From 81° afore port beam, to 2° on starboard side of keel aft = 173°. Then, from 61° afore, to 50° abaft starboard beam = 111°. Total 284°, or 25¼ points, nearly.

6° forward, and 6° aft on both sides = 24°, or 2¼ points, nearly.

7.

From 50° afore port beam, to 85° afore starboard beam = 315°, or 28 points.

6° forward on port side, 2° on starboard side = 8°, or ¾ of a point.

SUMMARY.

| WITH BOTH GUNS. | | | ADDITIONAL WITH SINGLE GUNS. | | |
|---|---|---|---|---|---|
| No. of Turret. | Degrees. | Points. | No. of Turret. | Degrees. | Points. |
| 1 | 315 | 28 | 1 | 8 | ¾ |
| 2 | 284 | 25¼ | 2 | 24 | 2⅛ |
| 3 | 277 | 24½ | 3 | 21 | 2 |
| 4 | 284 | 25¼ | 4 | 24 | 2⅛ |
| 5 | 277 | 24½ | 5 | 21 | 2 |
| 6 | 284 | 25¼ | 6 | 24 | 2⅛ |
| 7 | 315 | 28 | 7 | 8 | ¾ |
| Mean Command .. | 290° 51′ | 25¾ | Additional Mean Command .. | 18° 35′ | 1¼ |

This power of mean command exists when the mutual obstruction unavoidably presented by the turrets themselves is alone taken into account. But even if 50° be subtracted from it as a mean deduction for the further unavoidable obstructions presented by masts, hatchways, and the like, the remaining 240°, or more than 21 points of the compass, as a mean command for each turret, gives, says Halsted, a training-power unapproachable by any other system. The shaded spaces between the turrets, however, show the neutral surfaces, *untraversed by any fire*, to be sufficiently extensive to accommodate many of such further obstructions without any sacrifice of training whatever.

*Concentration and Direction of Fire.*—The whole fourteen guns, Fig. 614, can concentrate on points in direct line on either beam, 100 ft. distant from the guns of the central turret, No. 4, and can train from thence against ships or batteries, throughout an arc of 50° afore and abaft.

The four guns of 1, 2, and of 7, 6, can simultaneously concentrate on points, in direct line of keel forward and aft, 100 ft. distant from stem and stern. If engaged only forward, or only aft, this fourfold line-of-keel fire can be supplemented; if forward, by the alternate single guns of 6, 7; and, if aft, by those of 1, 2: all four of which command a line of fire of 87°, or only 3° from line of keel, forward and aft, on either side respectively. Whether chasing or chased, a fire of six guns out of fourteen, practically in line of keel, can thus be maintained.

To illustrate the bow and quarter fire:—If a radius of 300 ft. be struck from the centre of the middle cupola, it will describe two arcs practically equidistant from both bows and both quarters. And if an angle of 17°, or 1½ point, be measured from the same centre and extended on each side of the keel forward and aft, it will fix two points in each arc, 100 ft. distant, practically, from the nearest part of each bow and each quarter of the ship, as shown in plate. While the four guns of 1, 2, are still engaged in line of keel forward, six other guns can concentrate on the above point on the port bow; namely, the two guns each from 3, 6, and the single port guns from 4, 5, respectively. So, at the same time, the four remaining guns can concentrate on the other like point on the starboard bow; namely, the two guns of 7, and the single starboard guns of 4, 5; which two turrets can thus ply their single guns alternately on each of the above bow-points. But it is further obvious, on reference to Fig. 613, that Turret 1 can concentrate, or alternate, the fire of both its guns, as required, against either the starboard or port bow-point; while Turret 2 equally commands the starboard point; and the defence of the ship, in single or in general action, can thus be maintained with her whole fourteen guns—*as with an end-on broadside*—throughout an arc of 3 points, or only 17° divergent on each side of her line of keel forward. And similarly complete and symmetrical is her means of defence aft. Both guns of Turret 1, with the starboard single ones of 3, 4, can concentrate a fourfold fire on the point on the port quarter; while a sixfold fire pours on the point on the starboard quarter from the two guns each of 2, 5, backed by the single port guns of 3, 4; the whole four guns of 7, 6, being still engaged, if needs be, in line of keel aft, or both those of 7 firing, either upon the port or starboard quarter-point, and both those of 6 pouring their fire upon the port point.

The power of concentration, says Halsted, is as simple as it is perfect. It exists from the moment the turrets are "clear for action," without any complicated preparation or combination between them, and is carried out by simple direction for all or any turrets to direct their fire on any specified point of an enemy's hull within their command of training.

*Securing the Turrets.*—All means of securing the turrets in stress of weather are purposely omitted from the sectional design, Fig. 615:—1, in order not to complicate the drawing itself; 2, in order to keep the subject free for special study when actual construction shall be undertaken. But the following means have been fully considered, and are regarded by ablest mechanicians as ample for every practical purpose, though not incapable, of course, of further improvement.

*To prevent all Lateral Motion.*—Four or more powerful horizontal clamps strongly secured to under-side of upper deck, working with competent screws, and clasping or unclasping from opposite points the external circumference of turret.

*To prevent all Vertical Motion.*—Four or more powerful vertical or oblique chains or rods, hinged, as shown in Fig. 613, or otherwise removable, strongly binding down the turret to the stronger parts of the main deck around the turret-bed.

*Security in Action.*—The flanges, with the angle of cone given to the twenty-four steel rollers, and their steel roller-path—upon which, when in action, the turret revolves—supply ample means for the true and safe working of the turret in every state of weather when its guns can at all be used. But these means are further assisted by centering the floor of the turret down to the central pivot of the working shaft on the lower deck, by a system of diagonal trusses which connect the two: this arrangement fully providing against any other motion by the turret than its intended horizontal rotation.

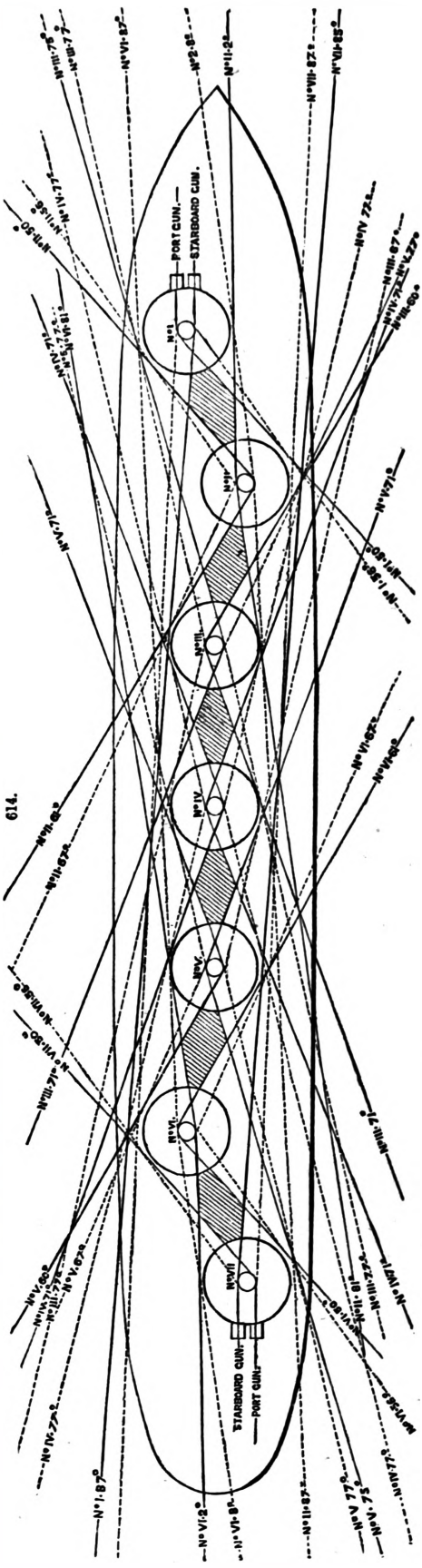
*On Upper Deck.*—A clearance of 3 in. surrounds the turret on the upper deck, rendering highly improbable any permanent choking of its action by any effects of shot. But the opening on that deck is surrounded by a strong box-girder, furnished with competent rollers, by which to meet any possible circumstances making it desirable for the turret to be supported at that point. A flexible flange or valve, as in the American monitors, keeps that opening water-tight, and any possible leakage will find its ready exit to the sea through the main-deck scuppers.

The following main details are, however, freely stated:—

*Construction.—Hull.*—The construction of the hull is on the same principle of combined longitudinal and transverse frames as in the 'Achilles,' 'Agincourt,' &c., and other British iron-clads of war; with an inner and outer skin-plating, as introduced by Mr. Scott Russell in the 'Great Eastern' steam-ship.

The extreme ends are made cellular and water-tight, with the same preparation for ramming as in the above-named ships. The whole of the intermediate space between the inner and outer skin-platings is subdivided into sectional water-tight compartments, arranged to be used for water-ballast, to compensate, when necessary, for consumption of fuel, and so on, and for maintaining the ship at her proper trim.

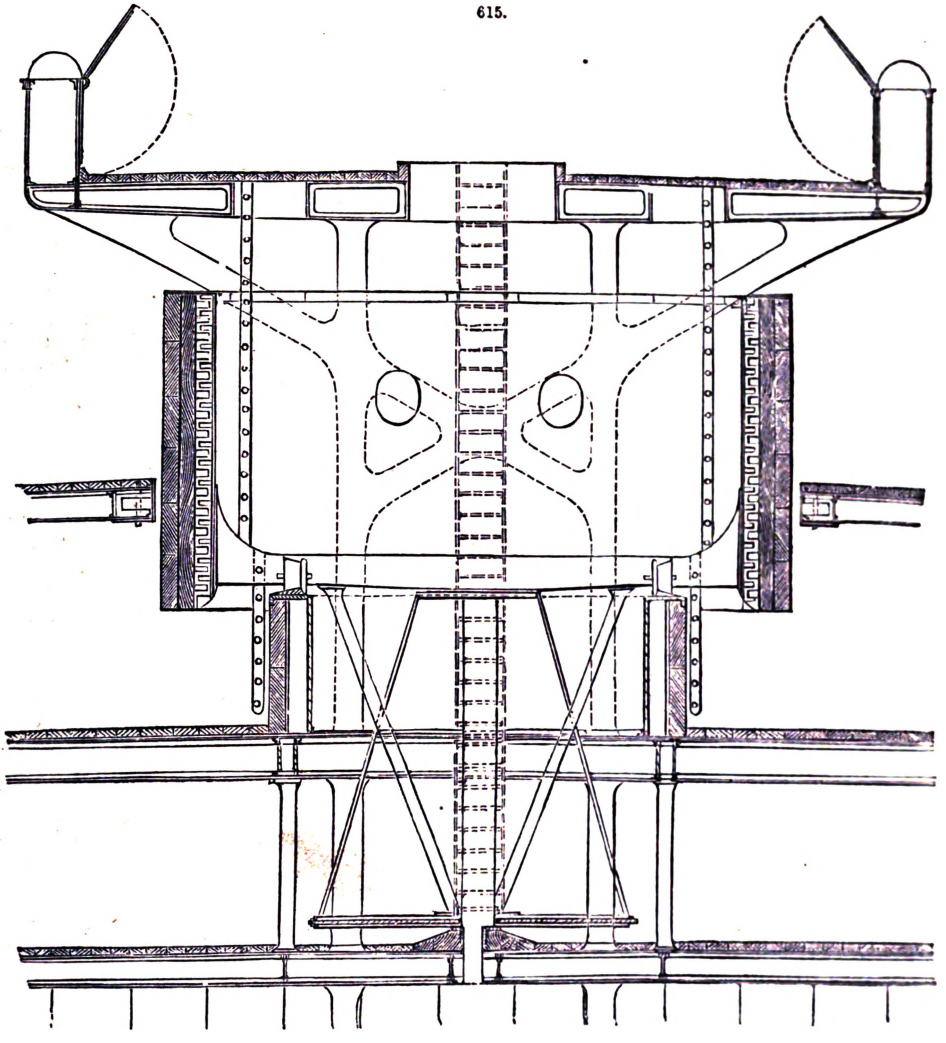
*Defensive Powers.*—Armour and backing has been considered in its compound character, and not simply in reference to the outer armour-plates. Throughout all classes and rates, as the guns are the same, so the armour and backing are of one character and thickness. The outer armour is 6 in. thick; next, teak 11 in. thick; next, 9 in. depth of Mr. John Hughes's hollow metal backing of $\frac{3}{4}$-in. iron; the bars in contact, running longitudinally from end to end of the




614.

ship, and securely riveted to the ¾-in. skin, as well as to the frames; thus combining with, and giving great strength and rigidity to, the whole structure. As in other iron-clads, the armour and teak-backing taper towards the ends, but not the Hughes' backing. The weight per square foot of the combined resisting media is, maximum 533 lbs., minimum 444 lbs., mean 488½ lbs. The resistance of the metal-backing is estimated as equal to 3-in. plating.

615.



*Main Deck*, in all classes, is level with the top of armour, and laid with 1¼-in. iron, covered with 6 in. of teak. The height out of water is, in ships of the line, 5 ft.; frigates, 4 ft.; corvettes, 3 ft. The only ship armour above main-deck level is that around the rudder and its working gear. The main-deck hatchways are limited to such as are requisite for provisioning, and so on; the turrets themselves constituting capacious hatchways for all other purposes. As with the upper decks of the American monitors, all main-deck hatchways are fitted with high coamings, and 1½-in. water-tight iron hatches, hinged, and always in place. This admits of the between-decks being flooded without the water finding its way below. Provision is made for getting rid of the water, in such case, by a large water-port beneath each main-deck gun-port on the broadside. The sides of the main deck are of ¾-plates unprotected, the armour being limited to the vital body of the ships, and all connected with the turrets. These sides are consequently liable to be riddled with shot-holes, through which the water might afterwards flood the main deck in heavy weather. In describing the turret, it will be shown that in such event complete access, as before, may still be maintained with the lower deck and all below it, even with 3 feet water over the main deck. The lower decks throughout are laid with ½-in. plates and 4-in. teak over; the upper decks with ¼-in. plates and 4-in. teak. The lower decks are 7 ft. beneath the beams; the main decks 8 ft.; except in the corvettes and ocean-despatch, where both are 7 ft.

*Spar Deck.*—This most important feature in aid of the whole undertaking is adopted from the rudimental spar decks, connecting turret with turret, in the American monitors. In its application here, as a war arrangement, the leading idea has been this,—the upper deck proper being regarded as if it were the main deck of an ordinary frigate. In such case the beams of the overhead deck would ordinarily receive end support from the walls or sides of the ship, as pierced with ports for

broadside-fire. But these beams would receive central supports also from two rows of stanchions, not fixed, but hinged, and removable as required. Now, the support of the spar deck represents, as it were, those two rows of central movable stanchions, converted into a system of fixed central support; the main-deck sides or walls of the ship being then altogether removed, so as to give free scope to a central, rotary, all-round turret-fire, substituted for that of the broadside. But the strength of that central system of trussed diagonal support for the spar deck enables it to fulfil also every office of a complete working upper deck, for boats, capstans, rigging, working ship, and the like, whether the turret guns beneath it be silent or in action. In all bad weather, and especially when steaming head to wind and sea, it thus constitutes a practical freeboard of ample height to secure all comfort and safety. The spar deck is constructed as a girder. Its lower convex skin is of $\frac{3}{16}$ steel plates, laid perfectly smooth; its upper convex is of $\frac{1}{2}$-in. iron, covered with 3-in. teak. Its edge is stiffened and strengthened by a continuous box-girder of $\frac{1}{2}$-in. plates, 4 ft. deep and 2 ft. wide, constituting the hammock-netting.

*Resistance of Spar Deck to Explosion of Turret Guns below.*—As two features of great novelty and importance are here involved, it is felt necessary thus to notice this subject. The question is obviously one of due strength. An experience of over three years, says Halsted, writing in 1867, has told us that decks of wood, with or without an underlay of iron plating, suffer no injury, beyond being blackened, by charges varying from 35 lbs. to 45 lbs. fired even less than one foot above their surface: and the nearest point of the under-side of any of these spar decks to the bore of the gun beneath it is 5 ft. 10 in. Again, long experience has determined that the angle of so-called explosive force diverges 45° from the circumference of the bore, in equal effect all round, but diminishing in effect directly as the distance. Thus the point where the explosion from the nearest muzzle will impinge on the nearest under-side of the spar deck above it will be increased to 8 ft. 9 in., presenting a smooth surface of steel. And if its strength be but equally resistant as that layer of a deck of wood, 1 ft. 4 in. distant, as in the 'Royal Sovereign,' which lies nearest to a muzzle above it, and suffices to resist all injury; it is clear no apprehension for these spar decks need be entertained. But if indeed it be found less than that wooden standard of sufficiency, then a further layer of iron plate, even to an inch in thickness, over the arc of impingement is easily added.

Figs. 613 and 615 illustrate other details of construction not here described.

Sea-going turret-ships, by Admiral Paris, Figs. 616, 617, 618, 619; taken from the 'Artizan' for April, 1869.

The subject of sea-going turret vessels, which is one of vast importance to this country, has just now acquired still greater interest from the fact lately disclosed by Mr. Childers, the present chief of the Admiralty, that our Government have at last determined to entirely leave off building wall-sided iron-clads, and construct only turret ships.

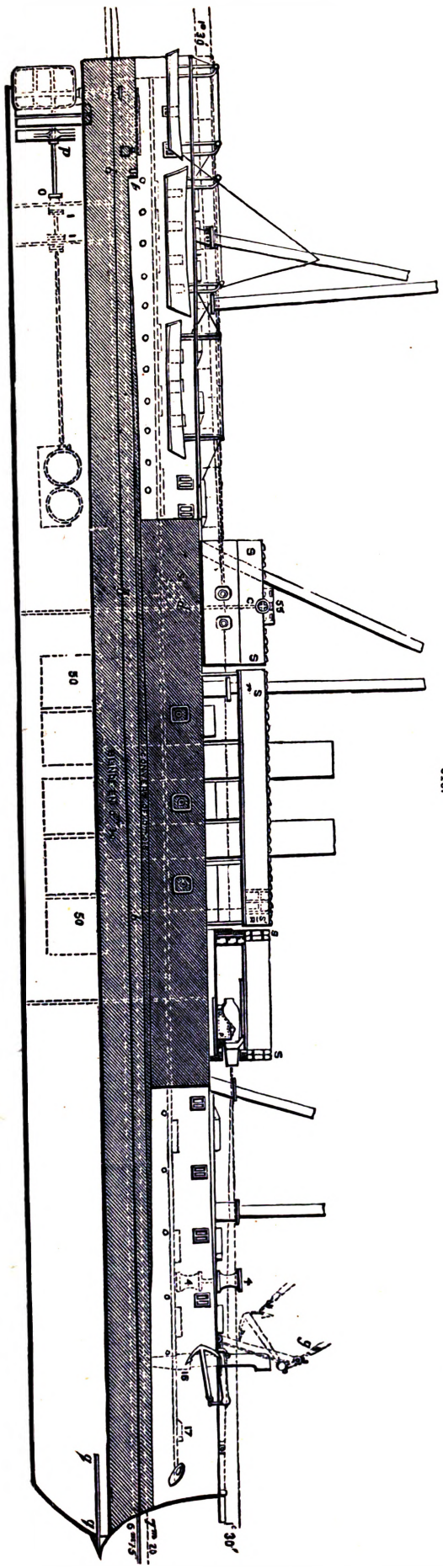
Few, if any, authorities upon this subject stand so deservedly high as Admiral Paris, who has devoted so many years to the study of its merits, and we have therefore given the following explanation of his views as communicated by him.

Since the first appearance of the 'Gloire' as a sea-going iron-clad, but few changes have arisen in the general features and form of vessels of this type. The only alteration of a notable character consists in the adoption of a *central battery*, which system has been rendered necessary, because, by reason of the increasing penetrative power of shot, it has been found practically impossible to carry armour of sufficient thickness over the whole length of wall-sided ships to afford them ample protection. One consequence of the introduction of *central batteries* has been a reduction in the number of guns carried by a vessel; thus ships of the magnitude of the 'Bellerophon' and 'Hercules' now carry only four or five guns on each side.

It is evident, however, that these guns will be more effectively used in a turret than in a central battery; and this is now beyond dispute, the doubts militating against the turret system having been cleared away by the trials of monitors in active warfare, and by their sea voyages. Also, as all iron-clads have been built of the same shape, that is to say, with vertical sides and rounded bottom, they commonly roll heavily, shipping water through their ports and over their bulwarks, and preventing the use of those guns which in the old ships of war would have probably been brought into action: to this defect must be added the danger arising from the rolling of the vessel, which tends to expose the weak or unarmoured parts of the vessel every few seconds. Hence at the present time it appears that, in the ordinary system of wall-sided iron-clads, the limited range of guns, the low height of their elevation above the surface of the water, and the rolling of the ships, are defects gravely impairing their other qualifications, which have been so greatly enhanced by the skill of many of our modern engineers.

There appeared, however, in the United States of America, a peculiar description of vessel, which was only designed for navigating rivers, but was found to possess a remarkable stability in a sea-way, only rolling about one-third as much as vessels of the ordinary build. The natural conclusion from this almost unexpected result is, let us adopt similar shaped vessels; or, in other words, let us build monitors. But if this form were adopted throughout the entire navy of any country, she would be unable to carry on a war in open sea in bad weather, as it is acknowledged to be unsuitable for a heavy sea. The problem, therefore, is how to obtain the advantages of stability and extensive range of fire as possessed by the American monitors, in vessels capable of navigating the ocean in all weathers. This problem Admiral Paris endeavoured to solve, after having had the advantage of studying the various models in the Paris Exposition, and having reliable information respecting the monitors, together with long experience at sea. To design a vessel which should be as free from rolling as a monitor; as seaworthy, and with as good accommodation, as vessels of the usual form; and carrying her guns a sufficient height out of the water, with an all-round fire, was his object.

As regards stability, or freedom from rolling, it is well known that a boat-hook floating in the water, and kept right by the weight of the iron end, is least affected by the waves. Again, a

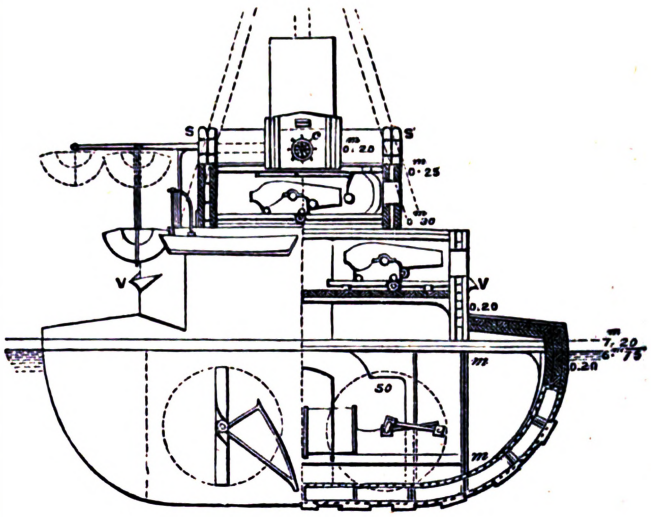



616.

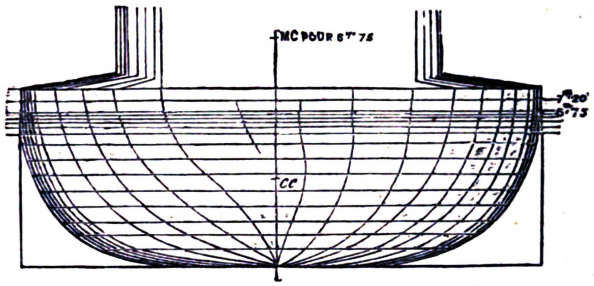
617.

plank weighted on the bottom side will not roll; while a body in the form of a sphere, or a cylinder, has no stability of its own, and requires a large amount of ballast to keep it upright. The contrast between the motion of different shapes of buoys in a heavy sea, is a simple illustration of varying stability. A body of almost equal specific gravity to, and which consequently has its upper side level with, the water, such as a boat filled with water, or a piece of ice, moves with the waves, but only so far. The first of these forms would, of course, be impossible, as the vessel would be impracticably deep; besides which, a complete immobility is undesirable. The merits of the circular form are about to be proved by the Winan's yacht, and presents many difficulties; while the monitors have proved, on a large scale, the influence of waves upon a body of a specific gravity nearly equal to water.

618.




619.




These three illustrations, applied to the usual construction of a vessel, which may be described as a semi-cylinder, with a parallelopipedon over it, show that it is the form of maximum rolling, especially if weight is fixed outside to add to the inertia. It is well known that a raft rolls less than a boat; while a boat-hook, floating close to them, is quite motionless, for which reason it has been employed as a wave-tracer for showing the rolling of ships and the motion of waves, and has been found to act very perfectly. It is, moreover, necessary to rely upon the well-established fact of the non-rolling of the monitors, as the excessive motion of iron-clad vessels have fully proved our ignorance of the laws which govern the motion of ships, because if any theory upon this point really existed, it would be unpardonable not to have applied it.

For this reason, when it was first proposed to construct iron-clad vessels, Admiral Paris proposed that a model should be built—say about 130 ft. long—with iron frames and wood planking fastened with screw bolts, thus making a composite vessel. With such a vessel experiments might have been tried with weights in every possible position; and after having experimented sufficiently, the boat might be hauled ashore, the planks removed, and the frames put in the furnace and afterwards bent, so as to form a vessel of some different shape upon which to try similar experiments. By these means a considerable amount of practical knowledge could have been obtained as to the best form of vessel for war purposes.

It has been already mentioned, the monitor is the best form of vessel for stability, and is also perfectly adapted to the smooth surface of rivers, where the ship's company have frequent opportunities to breathe pure air ashore, though they cannot be considered as adapted for long voyages at sea. The first monitor was sunk in weather which permitted another ship to use her boats; while the 'Weehawkee' and the 'Affondatore' suffered the same fate, in consequence of opening the hatches to breathe a little air after a battle.

The point, therefore, is to attain as near as possible to the non-rolling quality of the monitors, and avoid their unseaworthiness, which the Admiral endeavoured to accomplish in the following manner. It will be seen from Figs. 616, 617, 618, 619, that the midship section of the proposed vessels are formed of parts of circles for the sides with a flat bottom, the sides rising but a short distance above the water-line, and covered with a deck for a certain distance inwards: when the sides again rise to a sufficient height to admit of ports being placed well above water, this portion being long and narrow, somewhat similar to a river steamer in shape. Upon reference to the cross-sections, Figs. 617, 618, it will at once be observed that, with the exception of the comparatively narrow raised portion, the vessel is similar in section to a monitor, and consequently possesses the similar properties of stability. This element being the most important point, it was necessary to study it carefully, and, therefore, Paris calculated the positions of centre of *carène* (that portion of a vessel which is below the water-line, when floating in any position, whether

upright or inclined) and the metacentre, both when the vessel was upright and also when heeled over at various angles up to 20°, from which the following Table was obtained.

| Inclination. | Draught to lowest point of immersion. | Displacement of *carène*, P. | Distance of centre of *carène*: To water-line. | Distance of centre of *carène*: To longitudinal plan. | Height of metacentre over centre of *carène*. | Height of centre of gravity to water-line, + over − under. | Height of centre of gravity over centre of *carène*, a. | Value of $\rho - a$. | Moment of stability, M. | Momentum of sails, M'. | Value of $\frac{M}{M'}$. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m. | tons. | m. | m. | m. | | | m. | | | |
| Vessel upright | 6·750 | 8368 | 2·875 | 0·0 | 5·85 | − 0·58 | 2·30 | 3·55 | 29716 | 72766 | 0·408 |
| Inclined 5° .. | 6·765 | „ | 2·90 | 0·42 | 4·05 | − 0·60 | 2·31 | 1·74 | 14560 | .. | 0·209 |
| „ 10° .. | 6·795 | „ | 2·95 | 0·73 | 3·40 | − 0·62 | 2·335 | 1·065 | 8912 | .. | 0·106 |
| „ 15° .. | 6·840 | „ | 3·03 | 1·02 | 3·30 | − 0·65 | 2·375 | 0·925 | 7740 | .. | 0·092 |
| „ 20° .. | 6·92 | „ | 3·12 | 1·29 | 3·48 | − 0·70 | 3·415 | 1·085 | 9079 | .. | 0·107 |

Vessels of this form are notable clippers; but, for the sake of comparison, we will take a spread of canvas equal to that of an old three-decker with 3000 square mètres, the centre of effort being 26m·20 above the water-line. The Admiral then compared the moment of stability at various inclinations with that of vessels built upon the old system, and given in a Table in a most instructive work by M. Fréminville, sub-director of the school of Génie Maritime, entitled 'Guide du Marine,' which is as follows:—

| Names of Ships. | Value of $\frac{M}{M'}$ for the ships indicated. | Ratio of the stability of the proposed ship, Fig. 616, to that of each of the vessels named below, for inclinations of: Normal. | 5 deg. | 10 deg. | 15 deg. | 20 deg. |
|---|---|---|---|---|---|---|
| | | times. | times. | times. | times. | times. |
| 'Breslau,' 100 guns, with full complement .. | 0·082 | 5 | 2·55 | 1·29 | 1·12 | 1·30 |
| Stores having been used .. .. .. .. .. | 0·059 | 6·9 | 3·54 | 1·8 | 1·55 | 1·84 |
| 'Tage,' 90 guns, with full complement .. .. | 0·096 | 4·25 | 2·37 | 1·11 | 0·95 | 1·12 |
| Stores having been used .. .. .. .. .. | 0·078 | 5·1 | 2·69 | 1·36 | 1·18 | 1·37 |
| 'Breslau,' with full complement .. .. .. .. | 0·076 | 5·37 | 2·75 | 1·40 | 1·21 | 1·41 |
| 'Alceste,' 52 guns, with full complement .. .. | 0·067 | 6·09 | 3·12 | 1·58 | 1·37 | 1·60 |
| Stores having been used .. .. .. .. .. | 0·053 | 7·59 | 3·94 | 2·00 | 1·73 | 2·00 |
| 'Jeanne d'Arc,' 44 guns, with full complement .. | 0·063 | 6·47 | 3·31 | 1·68 | 1·46 | 1·70 |
| Stores having been used .. .. .. .. .. | 0·051 | 8·00 | 4·10 | 2·08 | 1·80 | 2·10 |
| 'Eurydice,' 30 guns, with full complement .. | 0·077 | 5·30 | 2·71 | 1·37 | 1·195 | 1·39 |
| 'Obligado,' 10 guns, with full complement .. | 0·065 | 6·27 | 3·21 | 1·63 | 1·41 | 1·64 |
| Stores having been used .. .. .. .. .. | 0·059 | 6·91 | 3·37 | 1·80 | 1·56 | 1·88 |

From these figures it will be seen that the stability of the proposed ship, Figs. 616, 617, 618, 619, which has been calculated for a light cargo, or at least for a mean one, is eight times that of some of the old ships after the stores were used; and if compared with the 'Tage,' with full complement of stores and provisions, the ratio is 4·25 times, the position of 616 being normal. But it is to be observed that at 5° the ship, Fig. 616, has 5 per cent. less stability compared with the 'Tage' with full complement, but 1·18 more after the stores have been used. It has also to be remarked that though the stability is a minimum at the angle of 15°, it rises afterwards, and at 20° is much higher.

Admiral Paris is aware that the comparison with the ships mentioned is not so fair as would be one with old ships having "tumbling home" sides, such as the 'Royal Louis,' and so forth, designed by M. Ollivier in 1750, and such as that proposed by the Admiral formerly. These have a *carène* like other ships—that is to say, 88m long, 18m·20 beam, and 8m draught but the upper deck would not be proportionately so wide as the more modern vessels, so that the metacentre would be motionless, as in the old class of ships, as shown in the work entitled 'L'Art Naval à Exposition de 1867.' The plan first proposed, and here alluded to, was but a first step towards the present arrangement.

It should here be observed that all the calculations relating to the present proposed form of turret-ships have been made in reference to the largest, shown in Figs. 616, 617, 618, 619, and proportionately reduced for others, of which the lines and proportions are relatively the same.

It may be of advantage to those engaged in the examination of such questions as that under present consideration to be made acquainted with the method pursued in the calculations to economize time and labour.

The calculation of the centre of *carène* for a ship when inclined is exceedingly tedious, wherefore the writer employed a term called the *mean section*, which is obtained by taking the arithmetical mean of the ordinates to each water-line, and setting off the height as obtained in this manner. Then is the centre of *carène* situate in the centre of this figure, as may be proved by arithmetically calculating a centre of *carène* according to Stirling's differential method, as employed by the Swedish constructor Chapman, the French naval architect Clairbois, and now adopted by naval architects generally.

Figs. 620, 621, 622, 623, represent one of Captain Cowper P. Coles' turret-ships lately designed: this is a vessel of 4272 tons, or about the same as the 'Bellerophon,' but with low freeboard from 3 ft. to 4 ft. out of the water. Her length between perpendiculars would be 320 ft.; beam, 53 ft.; two turrets, with guns 12 ft. above the water and 11 ft. horizontally from the sea. Between the turrets a deck-house is built, of the ordinary scantling of an iron ship, extending towards the vessel's sides at an angle that allows the turrets to cross their fire at 68° on the beam, and commanding an uninterrupted fire around bow and stern. This deck-house may be one, two, or three stories high, according to the accommodation required—in the present instance it is two stories high, surmounted by a hurricane deck 22 ft. out of the water. In the upper or second story, *b*, *b*, *b*, good accommodation is provided for the captain, the dining cabin being 24 ft. by 13 ft., with a suite of cabins in proportion, a commander's cabin, a wardroom, and four other cabins for officers, office, galley for the officers, a sick bay, baths, and w.cs. for both officers and men. The cabins and apartments on this deck would receive light and air from ports 2 ft. square, and 18 ft. out of the water, besides ventilation from the hatchways communicating with the hurricane deck. The lower or first story, *c*, *c*, *c*, would have mess-tables for 300 men, her fighting complement, a galley, midshipmen's, engineers', and warrant-officers' berths, besides four cabins for officers. This deck would receive air and light by means of ports 18 in. square, 11 ft. 6 in. out of the water, beside hatchways. All the hatchways on this deck leading below would have the means of being closed and kept water-tight the same as in monitors. The remaining nine cabins for officers would be on the lower deck, which corresponds with the 'Captain's' and 'Royal Sovereign's,' receiving light from deck-lights, and ventilation by tubes communicating direct with the outer air through the deck-house; there would also be provision made on this deck for messing 300 extra men, should it be required.

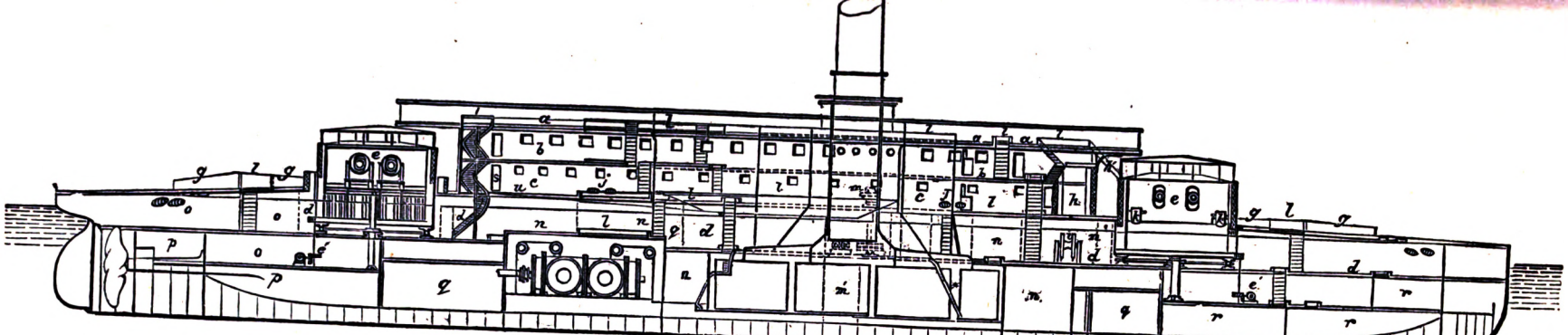
From the central position of the deck-house, as well as the horizontal and vertical distance from the water to the ports, and openings in it, free ventilation will be ensured in all weathers, whilst the comfort and accommodation will be second to no vessel in Her Majesty's navy.

From the form of this vessel above water, and the little resistance shown to wind or sea, lighter anchors and cables might be used than usual; but in this case we will suppose them to be the same weight as the '*Captain's.*' The cables would be led through fairleads at the edge of the bow along the upper deck, and through hawse-pipes, 8 ft. above the water, into the lower story of deck-house, where they would be worked by two steam capstans, one on each side, as in the 'Royal Sovereign.' The bower-anchors at sea would be stowed upon the deck without interfering with the firing or depression of the turret guns, and the spare anchors against the deck-house. The anchors can be worked on the bow or stern with equal facility. She would have the usual complement of boats, namely, two 42-ft. launches, two 32-ft. steam cutters, two 28-ft. life-boats, a captain's galley, and an officers' gig, which would be hoisted up by davits to the deck-house, and so arranged that at any moment they can be turned inboard when firing at sea.

Opinions will differ upon the question of masts; but, after considering the report of our iron-clad squadron, as well as other practical evidence, from which it appears that our ships as now masted are incapable as a fleet of manœuvring under sail without the aid of steam, the balance of advantage is, in Captain Coles' opinion, against such useless masts and sails, and in favour of fuel being substituted for the weight thus gained. Masts may be desirable to assist in decreasing the rolling propensities of high freeboard ships; but for vessels of low freeboard, with their decreased rolling, the Captain maintains that we can afford at once to sweep away the masts, gear and rigging, as antagonists to the steaming and fighting powers of war ships, and can at any time resort to temporary or small ones for fore and aft sails, such as 'Royal Sovereign' and 'Prince Albert' have, should it be considered desirable. In the stowage of fuel, weight and space have to be considered. In this vessel every 100 tons would make a difference of about 3 in. draught of water. In an armoured vessel the saving in weight, inherent to low freeboard, and the absence of masts gets rid of the greatest part of the difficulty under the head of weight; and the author of the design finds that, after giving ample accommodation, as before explained, for a crew of 300 men, and extra accommodation for 300 more men, making in all 600 men besides the officers, she would stow upwards of 1000 tons of coals, and even more, at the sacrifice of 3 in. immersion for every 100 tons.

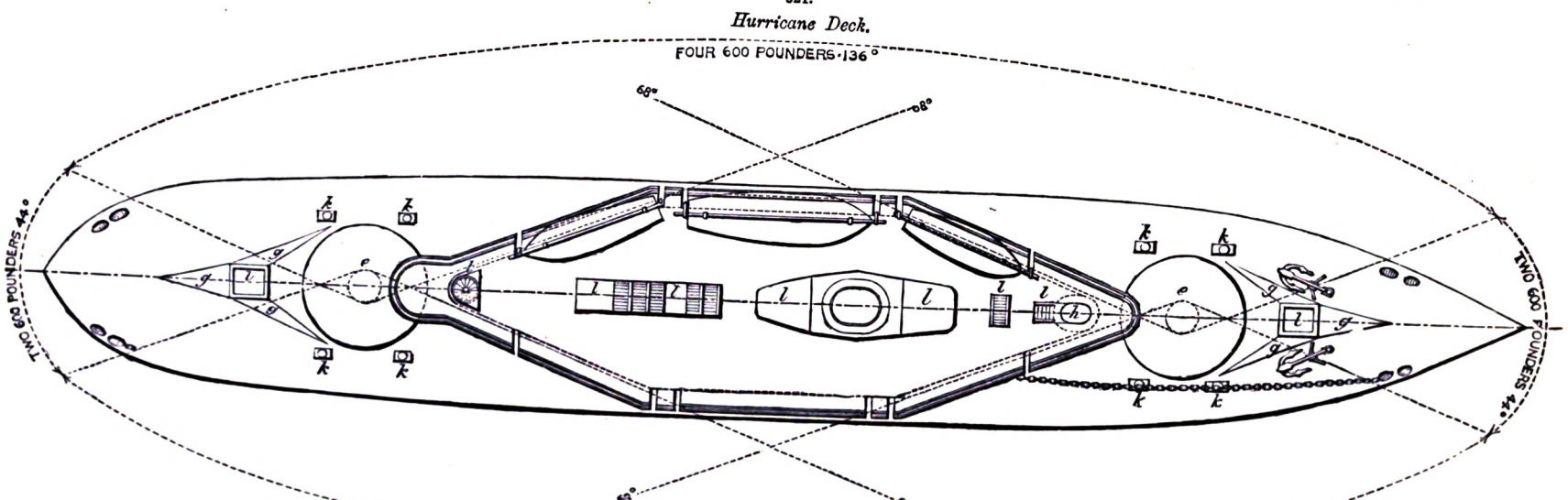
The armament would consist of two turrets, with 13-in. armour, carrying four of the heaviest guns that can be procured, say 600-pounders, 12 ft. above the water; and two pivot-guns, if thought expedient, on the hurricane deck, 22 ft. out of the water: the latter may be found advantageous for firing down upon a ship's decks; and it is believed a vigorous fire kept up by rockets and breech-loading rifles, from the position and height of this hurricane deck, would have a great effect upon an enemy's upper deck and open ports. Leaving the pivot-guns out of the question, the fighting powers of this ship's turrets would remain as follows: 88° of the circle are commanded by two 600-pounders, throwing a broadside of 1200 lbs., and the remaining 272° by four 600-pounders, throwing 2400 lbs.; and it will be observed that this ship can engage end-on with two 600-pounders, and at 22° from the line of keel, or only two points on the bow, with *four* 600-pounders, which would be her strongest point of attack; the importance of this is much increased when it is considered that all well-designed iron-clads will endeavour to present their bows to the enemy, when this ship would show the deflecting surface of a sharp protected bow, not more than from 3 ft. to 4 ft. out of the water, and a circular turret 9 ft. high above it; whilst in broadside-ships of approved model, a bulkhead some 20 ft. above the water is placed across the ship to protect their guns, which, when fighting end-on, presents a large and weak target at right angles to the enemy's raking fire, which might place their battery *hors de combat* before a chance of using their broadside-guns occurred.

In comparing the defensive powers of Captain Coles' ship with the high and weaker sides of broadside-ships, and of the 'Monarch,' when we say that her sides and turrets would be protected with 13 in. of iron, we give but a small idea of her great superiority, in some respects, over any



521.

*Hurricane Deck.*



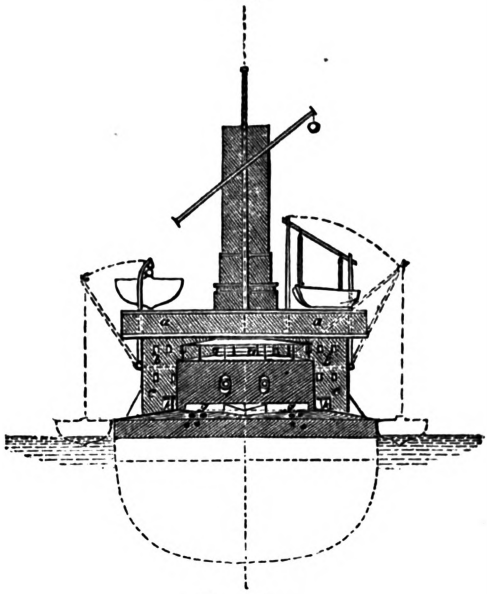

*Reference.*—*a*, *a*, *a*, Hurricane deck. *b*, *b*, *b*, Upper story, with accommodation for the captain and wardroom officers. *c*, *c*, *c*, Lower story, with accommodation for ship's company and junior officers. *d*, *d*, *d*, Lower deck. *e*, *e*, Turrets, with four 600-pounders. *e'*, *e'*, Engines for working turrets. *f*, *f*, Alternative of fixed breastworks round turret. See Figs. 622 and 623. *g*, *g*, *g*, Breakwaters. *h*, Pilot-house. *h'*, Slot in pilot-house for sight. *i*, Wheel. *j*, *j*, Hawse-pipes. *k*, *k*, Bitts. *l*, *l*, *l*, *l*, Ventilation and ladderways. *m*, *m*, Steam capstans and engines. *m'*, Chain lockers. *n*, Coals. *o*, *o*, *o*, Bread, slops, and stores. *p*, Provisions and spirits. *q*, *q*, Magazines. *r*, *r*, Stores, water, &c. *s*, *s*, *s*, Captain's apartments. *u*, Commander's cabin. *v*, *v*, *v*, Officers' cabins.

high freeboard vessel yet built, for her lowness of freeboard will give her antagonists but a sorry chance of hitting her, whilst her steadier platform will reduce the chances of her being hit below the water-line to the minimum. Lowness of freeboard may be said to facilitate being boarded; but, supposing an enemy to get upon the turret deck, he would have to take possession of the deck-house, which, from its position and height, as well as being enfiladed by the turrets, would be a matter of great difficulty.

Twin screws and no masts, in combination with the peculiar form of the vessel above water, showing so little resistance at her ends to the wind and sea, it is believed will assist in ensuring both speed and handiness to the fullest extent, as well as her absence of motion as compared with our present iron-clads, whose great loss of speed at sea may be attributed in a great measure to their floundering propensities. Her engines would be of 900 horse-power, and capable of propelling her at the rate of 14 knots. The principle of a deck-house can be modified to suit vessels of all sizes, carrying from one turret upwards.

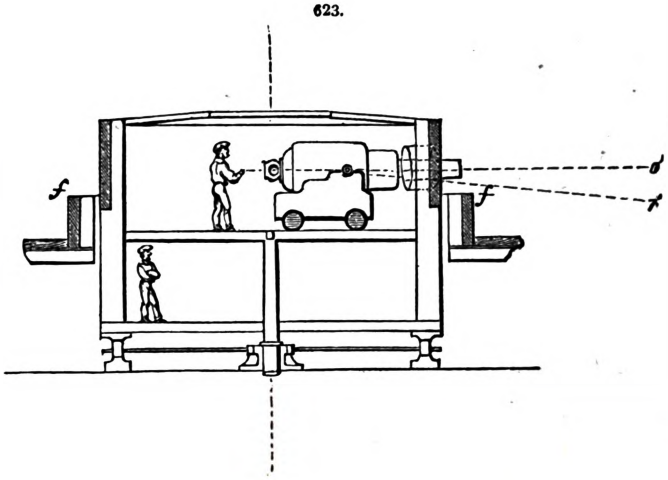
A one-turret ship would have the deck-house extending within about 10 ft. of the stern, balancing the turret by the other weights in the ship. A three-turret ship would have the third turret mounted on the hurricane deck before the funnel, bringing four guns right ahead. A four-turret ship would have the second and third turrets mounted at each end of the hurricane deck, bringing four guns right ahead and astern. It might be thought advisable in some instances to make the upper turrets of lighter iron than the lower ones, merely covering the guns mounted in pairs on turn-tables by a light iron turret, protecting their crews from rifles, grape, and canister.

622.



Bow View.

623.



Fixed Breastwork round Turret and Two-story Turret.

BAY. Fr., *Baie (de porte, de fenêtre)*; Ger., *Öffnung für Thür oder Fenster*; Ital., *Apertura*; Span., *Abertura en una pared.*

In builders' work, the space or extent embraced by one mode of construction, as a *bay of joists*, which is the surface covered by the joisting filled in between any two binding-joists; or a *bay of roofing*, which is the part filled in with common rafters between a pair of principal rafters.

The openings between the supports of a *bridge* are also called *bays.*

BAY OF JOISTS. Fr., *Panneau, Assemblage de Charpente*; Ger., *Füllung, Fachwerk*; Ital., *Commettitura*; Span., *Luz de traviesas.*

See Bay.

BAY OF ROOFING. Fr., *Travée de comble*; Ger., *Dachstuhlfette, Dachlatten*; Ital., *Scompartimento del tetto*; Span., *Luz de cobertizo.*

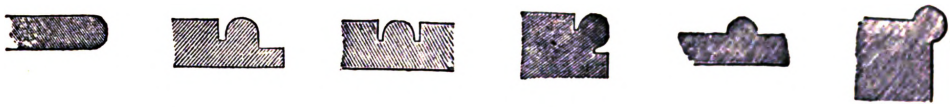
See Bay.

BEAD. Fr., *Baguette*; Ger., *Riefe oder Stab*; It., *Astragalo*; Sp., *Astragalo, Tondino*; *Junquillo.*

A moulding on wood or other material, generally forming, in section, a part of a circle, is designated a bead, which when on wood it is said to be *struck* on if formed with a plane which cuts the wood into the shape required.

A bead on the edge of a board, as shown in Fig. 624, is called a *nosing;* if on the face, but flush with the surface, and with one *quirk* only, as in Fig. 625, it is called a *quirk-bead.* But if with two quirks, Fig. 626, it is called a double quirk-bead; and if struck on the angle of a piece of work, Fig. 627, it is called a *return-bead.*

624. 625. 626. 627. 628. 629.



A bead projecting beyond the surface, Figs. 628, 629, is called a *cock-bead,* and sometimes a *cocked bead.*

*Bead and Batten Work.*—An expression used by carpenters to denote a rough style of work composed of battens with a bead run along the edge in the direction of the grain of the wood.

*Bead-butt.*—A term in joining applied to work framed in panels, when the latter are flush with the framing and a bead is struck or run on two sides only of the panel in the direction of the grain of the wood. The ends of the bead are made to stop or butt against the rails. See DOOR.

*Bead-flush.*—A term applied to framed work, which differs from the last, in having the bead run on the framing instead of on the panel, and in being all round, instead of on two sides only.

BEAM. FR., *Poutre;* GER., *Balken, Träger;* ITAL., *Trave;* SPAN., *Viga, Tirante.*

A beam is a piece of timber or metal, or both combined, used for sustaining a weight, or counteracting forces by tension and compression in the direction of its length, and by widening and narrowing in the directions of the breadth and thickness.

The word beam in builders' work is most frequently subjoined to another word, used adjectively or in apposition, to show its use or form, as *binding-beam, box-beam, built-beam, camber-beam, collar-beam, hammer-beam, dragon-beam, straining-beam, tie-beam, trellis-beam, trussed-beam,* and so on. See STRENGTH OF MATERIALS.

BEAM-FILLING. FR., *Maçonnerie de remplissage au niveau des poutres;* GER., *Mauerwerk zwischen der Balkenlage;* ITAL., *Riempimento;* SPAN., *Relleno.*

Masonry, brickwork, or concrete filled in from the level of the under-edges of the beams to that of their upper edges, is known as *beam-filling.* Beam-filling occurs either between joists or floor-beams, or in filling up the triangular space between the top of the wall-plate of the roof and the lower edges of the rafters, or even to the under-surface of the boarding or lath for slates, tiles, or thatching. This operation is necessary in garret-rooms, where the walls form sides of apartments, and where the tie-beams are placed above the bottom of the rafters.

BEARER. FR., *Lierne;* GER., *Bindesparren;* ITAL., *Sosteyno, Portante;* SPAN., *Cadena.*

Generally, this term is applied to any member of a structure which has to support a weight above it, as the joists in a flat roof, or the short pieces nailed to the rafters to support the gutter-board in a roof-valley, Fig. 630.

630.

The term may also be applied to any beam, whether of wood or iron, placed horizontally, which has to support a weight above it, as to a bressummer, which is only a particular application of a bearer.

BEARING. FR., *Collet;* GER., *Lager;* ITAL., *Colletto;* SPAN., *Punto de apoyo.*

Bearing of a girder or beam is the portion of it which rests on the supports.

Timbers or lintels let into a wall have usually a bearing of 9 in. at each end; stone steps should also have a bearing of 9 in.

The bearing of joists or other beams supported at both ends is regulated by the resistance of the material to crushing. A bearing of 4½ in. on the sleepers or wall-plates is usually considered sufficient in ordinary dwelling-houses.

Girders and beams are said to have a solid bearing when supported throughout their whole length. But in the case of sills, and so forth, when not so supported, they are said to have a false bearing.

The *bearing-distance* is the unsupported part between the bearings.

BEARING OUT.

This expression, generally applicable to new work, is used by painters to imply that a third, fourth, or fifth coat of paint has been so fully and evenly laid upon the previous ones, that the original colour of the body, the knotting, the priming, and the under-coats, cover well, and give no sign of disfiguring the glossy surface of the finishing coat.

BED. FR., *Semelle;* GER., *Tragseite;* ITAL., *Corso.*

In masonry and brickwork is the upper and under side of a stone or brick. In arch-stones the beds are the joints which radiate towards the centre. In slates the under-side is the bed.

Stones are usually specified to be laid on their quarry-bed, that is, the same relative position they had before they were quarried.

In builders' measurements the term beds and joints is used to designate all the parts of a stone covered in the work, in contradistinction to the face. The term also includes the back, if it be measured.

BEDDING TIMBERS, THE PROCESS OF. FR., *Poser les racinals;* GER., *Legen der Grundhölzer;* ITAL., *Fare il letto alle travi.*

*Bedding Timbers.*—Laying them on a wall or otherwise on a bed of mortar, cement, or putty, so that the bearing may be solid or uniform throughout. Wall-plates and sleepers are bedded in

this way. Care should be taken when bedding timbers to allow a free circulation of air around them, otherwise they are liable to rapid decay, particularly if in contact with lime-mortar in a moist state, as the hydrate of lime in the mortar abstracts the carbonic acid gas from the wood, which hastens its decay.

*Bedding Stone.*—See SETTING.

BED-PLATE. FR., *Plaque de fondation;* GER., *Grundplatte;* ITAL., *Piastra di fondazione;* SPAN., *Plancha de cimiento, carrera.*

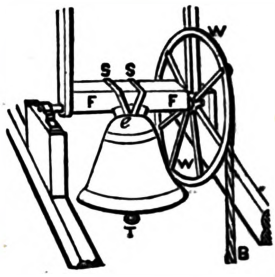
A *bed-plate* or *bed-piece* is the principal or foundation framing or piece, in machinery, by which the other parts are supported and held in place; the bed. It is also called the *base-plate* and the *sole-plate.*

BEETLE. FR., *Maillet;* GER., *Holzschlegel;* ITAL., *Mazzuolo;* SPAN., *Maleta.*

Beetle is a name given to a heavy mallet or wooden hammer, used to drive wedges, beat pavements, and the like. The term beetle is also applied to a machine used to produce figured fabrics by pressure from corrugated or indented rollers.

BELL. FR., *Cloche;* GER., *Glocke;* ITAL., *Campana;* SPAN., *Campana.*

631.




A bell is a hollow metallic vessel, which gives forth a clear, musical, ringing sound on being properly struck. The most common form of bell is shown in Fig. 631. In this form it is expanded at the lower part, is furnished at the top with an ear *e*, for the purpose of suspension, and has within it a tongue or clapper T, by the blow of which the sound is produced; S S, straps which secure the bell to the rock-shaft F, F; B is the bell-rope, and W W the vibrating wheel.

Another form, especially of small bells, is that of a hollow body of metal perforated, and containing a loose solid ball, to make a sound when it is shaken.

In the formulas, Table I., D = the diameter of the bell at the mouth, in inches; $d$ = the diameter of the bell at the crown; $h$ = height of the bell from the mouth to the crown; S = the thickness of the sound-bow, in inches; W = weight of the bell in lbs. avoirdupois (7000 grains = 1 lb. avoirdupois, and 5760 grains = 1 lb. Troy); $n$ = the number of vibrations a second, corresponding with the key-note of the bell, see Table II.; $k$ = the coefficient, expressing the relative thickness of the sound-bow to the diameter of the bell—it varies from ·07 to ·08. In peals of bells the sound-bow is generally put, S = ·08 × D for the triple; S = ·07 × D for the tenor; and the intermediate bells in the peal, proportions lying between these for the respective sound-bows.

TABLE I.

$$W = 0{\cdot}25\ D^2\ S \quad .. \quad .. \quad [1]$$

$$W = \frac{D^4\ n}{232000} \quad .. \quad .. \quad [2]$$

$$W = 0{\cdot}25\ D^3\ k \quad .. \quad .. \quad [3]$$

$$n = 58000\ \frac{S}{D^2} \quad .. \quad .. \quad [4]$$

$$n = 232000\ \frac{W}{D^4} \quad .. \quad .. \quad [5]$$

$$n = 58000\ \frac{k}{D} \quad .. \quad .. \quad [6]$$

$$D = 2\sqrt{\frac{W}{S}} \quad .. \quad .. \quad [7]$$

$$D = 240{\cdot}83\sqrt{\frac{S}{n}} \quad .. \quad [8]$$

$$D = 21{\cdot}947\sqrt[4]{\frac{W}{n}} \quad .. \quad [9]$$

$$D = \sqrt[3]{\frac{4\ W}{k}} \quad .. \quad .. \quad [10]$$

$$D = 58000\ \frac{k}{n} \quad .. \quad .. \quad [11]$$

$$S = \frac{n\ D^2}{58000} \quad .. \quad .. \quad .. \quad [12]$$

$$S = \frac{4\ W}{D^2} \quad .. \quad .. \quad .. \quad [13]$$

$$S = k\ D \quad .. \quad .. \quad .. \quad .. \quad [14]$$

$$k = \frac{S}{D} \quad .. \quad .. \quad .. \quad .. \quad [15]$$

$$k = \frac{4\ W}{D^3} \quad .. \quad .. \quad .. \quad [16]$$

$$W = D\ d\ S\ (0{\cdot}5 - 0{\cdot}0002816\ d) + {\cdot}00375\ h\ d^2\ S \quad .. \quad .. \quad [17]$$

*Example* 1, to illustrate [1], Table I.—Required the weight (W) of a bell, the diameter D = 60 in., and the thickness of the sound-bow S = 4·8 in.

$$[1]. \quad {\cdot}25\ D^2\ S = W = {\cdot}25 \times 60^2 \times 4{\cdot}8 = 4320 \text{ lbs.}$$

*Example* 2.—A bell of 2636·4 lbs. (W) is to be constructed with a sharp note, putting for the sound-bow K = ·075; what is the diameter (D) of the bell?

$$\text{From Table I., [10], } D = \sqrt[3]{\frac{4\ W}{k}} = \sqrt[3]{\frac{4 \times 2636{\cdot}4}{{\cdot}075}} = 52 \text{ in.}$$

*Example* 3.—Required the diameter (D) of a bell with the key-note D♯ in the first octave above zero, the bell to be light with a full note.

In this case $k$ = ·07, and $n$ = 152·25. Table II.

$$\text{D, the diameter} = 58000\ \frac{k}{n} = \frac{58000 \times {\cdot}07}{152{\cdot}25} = 26\tfrac{3}{4} \text{ in.} \quad [11] \text{ Table I.}$$

*Example* 4.—Required the key-note of a bell with D = 44 in., and S = 3·52 in.

$$[4]. \quad n = 58000 \times \frac{3{\cdot}52}{(44)^2} = 58000\ \frac{S}{D^2} = 105{\cdot}45.$$

In Table II. the nearest number 105·45, in the first octave below zero is 107·63, which answers to the key-note A.

TABLE II.—VIBRATIONS A SECOND = $n$.

| Key-Note. | BASS. | | | ZERO. | TREBLE. | |
|---|---|---|---|---|---|---|
| | 3rd Octave. | 2nd Octave. | 1st Octave. | 1st Octave. | 2nd Octave. | 3rd Octave. |
| C | 16·000 | 32·000 | 64·000 | 128·00 | 256·00 | 512·00 |
| C♯ | 16·947 | 33·895 | 67·790 | 135·58 | 271·00 | 542·32 |
| D | 17·960 | 35·920 | 71·840 | 143·68 | 287·36 | 574·72 |
| D♯ | 19·027 | 38·055 | 76·110 | 152·22 | 304·44 | 608·88 |
| E | 20·159 | 40·318 | 80·636 | 161·27 | 322·54 | 645·09 |
| F | 21·357 | 42·715 | 85·430 | 170·86 | 341·72 | 683·44 |
| F♯ | 22·627 | 44·255 | 90·510 | 181·02 | 362·04 | 724·08 |
| G | 23·972 | 47·945 | 95·890 | 191·78 | 383·56 | 767·12 |
| G♯ | 25·398 | 50·797 | 101·59 | 203·19 | 406·37 | 812·75 |
| A | 26·908 | 53·817 | 107·63 | 215·27 | 430·53 | 861·07 |
| A♯ | 28·508 | 57·017 | 114·03 | 228·07 | 456·13 | 912·27 |
| B | 30·204 | 60·409 | 120·82 | 241·63 | 483·27 | 966·54 |
| C | 32·000 | 64·000 | 128·00 | 256·00 | 512·00 | 1024·0 |

*Example* 5.—A bell has to be cast with the key-note C in first octave below zero; required the diameter D, when the weight = 6561 lbs.

We find in this case $n = 64$, Table II.

$$\therefore \text{[9], Table I., } D = 21{\cdot}947 \sqrt[4]{\frac{6561}{64}} = 69{\cdot}84 \text{ in.}$$

*Example* 6.—What is the thickness (S) of the sound-bow of the bell in Example 5, D = 69·84; $n = 64$?

$$\text{From [12], Table I., } S = \frac{n D^2}{58000} = \frac{64 \times (69{\cdot}84)^2}{58000} = 5{\cdot}38 \text{ in.}$$

TABLE III.

| Abscissa $x$. | Ordinate $y$. | THICKNESS OF METAL. | | | |
|---|---|---|---|---|---|
| | | S = 1. | S = ·07 D. | S = ·075 D. | S = ·08 D. |
| 1 | 0·4142 | 1 | ·700 | ·750 | ·800 |
| 1½ | 0·686 | ·800 | ·560 | ·600 | ·640 |
| 2 | 0·867 | ·653 | ·459 | ·490 | ·522 |
| 2½ | 0·974 | ·547 | ·382 | ·410 | ·437 |
| 3 | 1·025 | ·474 | ·331 | ·355 | ·379 |
| 3½ | 1·030 | ·423 | ·295 | ·317 | ·338 |
| 4 | 1·000 | ·380 | ·266 | ·285 | ·304 |
| 4½ | 0·955 | ·351 | ·245 | ·263 | ·281 |
| 5 | 0·875 | ·327 | ·228 | ·245 | ·261 |
| 5½ | 0·775 | ·301 | ·211 | ·226 | ·241 |
| 6 | 0·665 | ·291 | ·203 | ·218 | ·233 |
| 6½ | 0·530 | ·286 | ·200 | ·214 | ·228 |
| 7 | 0·390 | ·279 | ·195 | ·209 | ·223 |
| 7½ | 0·235 | ·272 | ·190 | ·204 | ·217 |
| 8 | 0·075 | ·267 | ·186 | ·200 | ·213 |
| 8·74 | 0·780 | ·333 | ·233 | ·250 | ·266 |

*Example* 7.—If D = 50 in., $d$ = 27 in., $h$ = 36, and S = 4·, what is the weight (W) of the bell?
From [17], Table I., $W = D\,d\,S\,(\cdot5 - \cdot0002816\,d) + \cdot00375\,h\,d^2\,S = 50 \times 27 \times 4\,(4{\cdot}9923968) + 393{\cdot}66 = 3092{\cdot}13936$ lbs.

When a bell is to be constructed, we generally have the weight or key-note given, the diameter and sound-bow are calculated by the preceding formulas and examples, and we may then proceed with the construction, shown in Figs. 632, 633, 634.

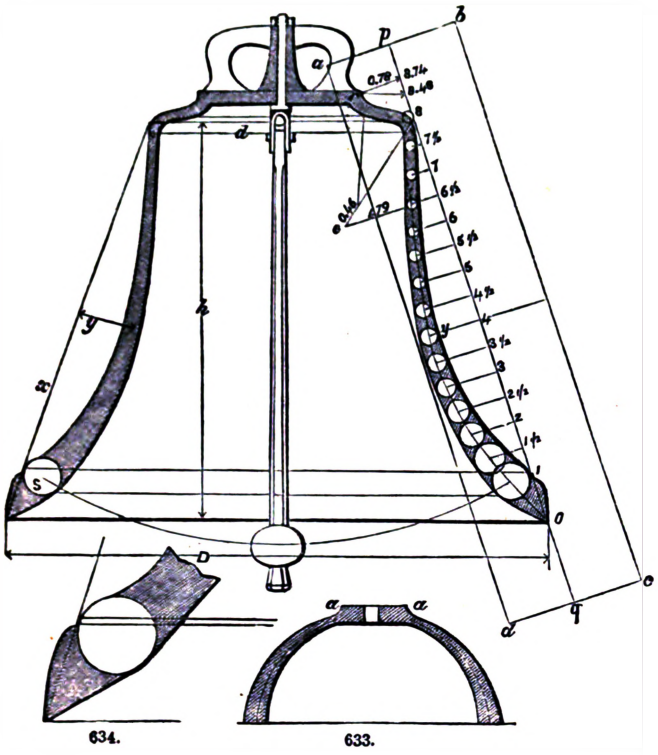
The diameter of the bell at the mouth is divided into 10 equal parts, called strokes, which then is the scale and measurement for the construction.

Shrinkage to be allowed for $\frac{3}{16}$ths of an inch to the foot.

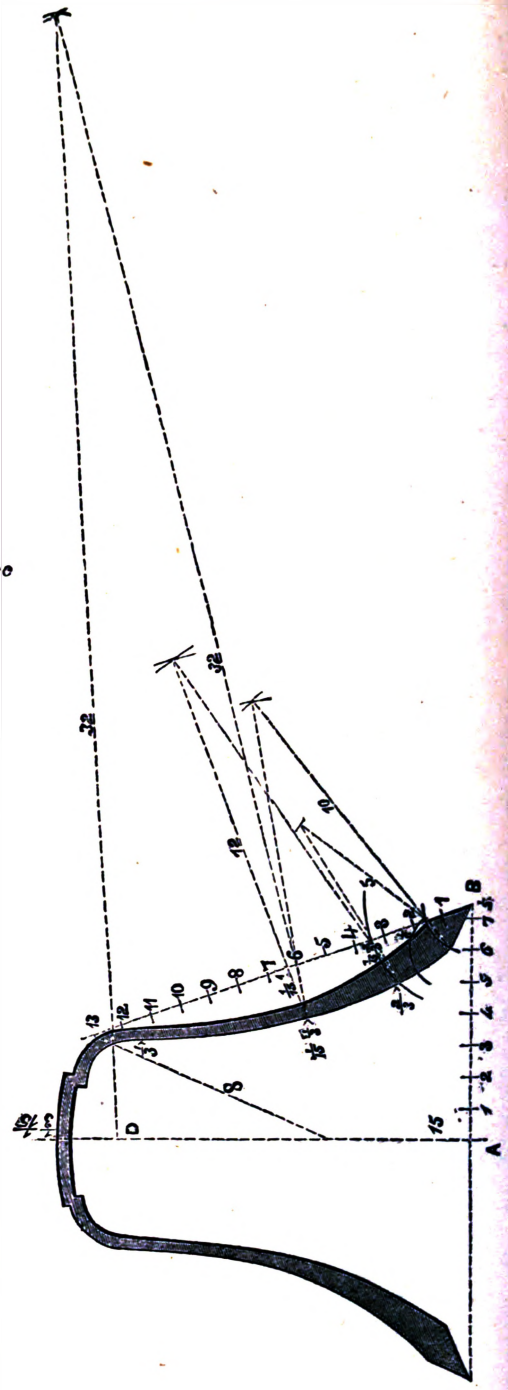
The section of a bell is generally laid out on a piece of board represented by the lines $a$, $b$, $c$, $d$, which then is cut out and used for turning up the mould for the bell. The board should be about 11 strokes long, and 2·5 strokes wide. Through the centre of the board draw the line $p$, $q$, parallel

to $b$, $c$; bisect the line $p$, $q$, and set four (4) strokes from the bisecting point towards each end; divide the strokes into halves, and number them as shown on the accompanying drawing, Fig. 632. Through each division draw lines at right angles to $p$, $q$, set off the corresponding ordinates $y$ expressed in strokes, Table III., and join them by a curve-line, which then will be the centre of thickness of metal in the bell.

632.




635.



At the end of the first ordinate, as a centre, draw a circle with a diameter equal to the desired thickness of the sound-bow, which should be from 0·7 to 0·8 stroke. At every succeeding ordinate draw a circle with the diameter noted in Table III.: for instance, if the thickness of the sound-bow is 4½ in., then the thickness of metal or diameter of the circle at the third ordinate will be $4·5 \times 0·474 = 2·133$ in.; but if the sound-bow is 0·7, 0·75, or 0·8 stroke, the thickness of metal at the third ordinate will be 0·331, 0·355, or 0·379 stroke. When all the thicknesses are thus drawn, draw the two lines tangenting the circles on each side of the centre line of the metal.

From 0 to 1 make a moulding of 0·1 stroke thick over the line, as shown in Fig. 633. Prolong the 6½ ordinate, and set off 1·79 stroke to $e$, which then is the centre for the curve on the top; draw the arc through the centre of the small circle at the eighth ordinate; join $e$, 8, set off from $e$, 0·46 stroke to the centre for the inside curve at the top.

Thickness of metal of the top should be 0·3 the sound-bow at 8, and 0·333 at $r$. Draw the ordinate at 8·74, set off 0·78 to $r$, join $r$ and the abscissa 8·48, and prolong the line through $r$; then finish the drawing, as shown in Fig. 632.

When the board is cut out and ready for turning the mould, it must be carefully set, so that the outside diameter of the crown will be half the diameter of the mouth of the bell.

This form of bells gives the greatest possible gravity of tone with the least possible quantity of metal. Bells can be made almost in any form without seriously affecting the quality of tone; but the thickness of metal should always be in proportion as the square of the diameter, taken at the centre of the metal, as in Fig. 634.

TABLE IV.—PROPORTIONS OF A PEAL OF EIGHT BELLS.

| Bells. | Key-Note. | *n.* | *k.* | S. in. | D. in. | W. lbs. | Clapper. |
|---|---|---|---|---|---|---|---|
| | | | | | | | lbs. |
| Tenor .. | D | 71·84 | 0·070 | 3·95 | 56·5 | 3156 | 63 |
| 2nd .. | E | 80·64 | 0·071 | 3·62 | 51·1 | 2366 | 48·6 |
| 3rd .. | F♯ | 90·51 | 0·072 | 3·32 | 46·1 | 1765 | 37·2 |
| 4th .. | G | 95·89 | 0·073 | 3·22 | 44·2 | 1575 | 34·1 |
| 5th .. | A | 107·63 | 0·075 | 3·08 | 40·5 | 1262 | 28·1 |
| 6th .. | B | 120·82 | 0·077 | 2·85 | 37·0 | 976 | 22·4 |
| 7th .. | C♯ | 135·58 | 0·079 | 2·67 | 33·8 | 763 | 18·2 |
| Triple .. | D | 143·68 | 0·080 | 2·58 | 32·3 | 673 | 16·8 |

*Clapper.*—The weight of the clapper should be from $\frac{1}{40}$th to $\frac{1}{50}$th the weight of the bell; the smaller bells take the largest clappers.

The tracing of bells rests upon a fixed basis, called the *Bell-scale*, or *Jacob's Staff*, the result of long experience, and handed down from generation to generation among founders. It depends upon certain proportions which, like the modules in architecture, serve to regulate and to harmonize the different parts of the bell. The *bow*, or, in other terms, the thickest part of the bell, constitutes the principle of all the measurements.

The following Table, which we borrow from M. Guettier's work on Casting, gives the diameter of bells, and the thickness of the bow, from the weight of 3 kilos. to 12,000 kilos. It is nothing more than a scale, presented under another form and in metrical measure.

TABLE V.

| Weight of Bells. | Thickness of Bow. | Large Diameter. | Weight of Bells. | Thickness of Bow. | Large Diameter. | Weight of Bells. | Thickness of Bow. | Large Diameter. |
|---|---|---|---|---|---|---|---|---|
| 3 | ·008 | ·120 | 200 | ·047 | ·705 | 3500 | ·123 | 1·845 |
| 4 | ·011 | ·165 | 250 | ·050 | ·750 | 4000 | ·128 | 1·920 |
| 5 | ·013 | ·185 | 300 | ·055 | ·825 | 4500 | ·134 | 2 010 |
| 6 | ·015 | ·225 | 350 | ·058 | ·870 | 5000 | ·137 | 2·055 |
| 10 | ·019 | ·285 | 400 | ·060 | ·900 | 5500 | ·141 | 2·115 |
| 15 | ·021 | ·315 | 450 | ·063 | ·945 | 6000 | ·146 | 2·190 |
| 20 | ·022 | ·330 | 500 | ·065 | ·975 | 6500 | ·150 | 2·250 |
| 25 | ·023 | ·345 | 600 | ·068 | 1·020 | 7000 | ·154 | 2·310 |
| 30 | ·025 | ·375 | 750 | ·074 | 1·110 | 7500 | ·158 | 2·370 |
| 35 | ·027 | ·405 | 1000 | ·081 | 1·215 | 8000 | ·160 | 2·400 |
| 40 | ·028 | ·420 | 1250 | ·087 | 1·305 | 8500 | ·164 | 2·460 |
| 45 | ·029 | ·435 | 1500 | ·093 | 1·395 | 9000 | ·168 | 2·520 |
| 50 | ·030 | ·450 | 1750 | ·098 | 1·470 | 9500 | ·170 | 2·550 |
| 75 | ·034 | ·510 | 2000 | ·103 | 1·545 | 10000 | ·173 | 2·595 |
| 100 | ·037 | ·555 | 2250 | ·108 | 1·620 | 11000 | ·181 | 2·715 |
| 125 | ·040 | ·600 | 2500 | ·110 | 1·650 | 12000 | ·190 | 2·850 |
| 150 | ·043 | ·645 | 2750 | ·114 | 1·710 | | | |
| 175 | ·045 | ·675 | 3000 | ·117 | 1·755 | | | |

Several methods are employed for tracing bells. The one mostly used in France gives 15 thicknesses of the bow to the diameter, 7½ to the diameter of the crown, 12 to the line joining the lower ridge of the bell and the base of the crown, and finally 32 to the great radius serving to trace the profile of the bell proper. Fig. 635, where each line of construction has its dimension marked—the thickness of the bow being taken as unity—will be sufficient to show how the process is carried out.

BELL-CRANK. FR., *Levier brisé*; GER., *Winkelhebel*; ITAL., *Zanca*; SPAN., *Cigüeña*.

An iron or brass lever in the shape of a quadrant of a circle, attached to an iron holdfast which is driven into a wall, receives the name of bell-crank, because it is used to connect bell-wires at the angles or corners of a room. Any rectangular lever, Fig. 636, by which the direction of motion is changed through an angle of 90°, is termed a bell-crank.

636.

BELL-HANGING, DOMESTIC. FR., *Pose des sonnettes*; GER., *Befestigen der Glockenzüge in den Wohnhäusern*; ITAL., *Mettere i campanelli*.

The art of domestic bell-hanging is quite modern. It is believed not to have been in practice much before the present century. Within the writer's recollection it was usual, in even the best houses, to expose the wires to view along the walls and ceilings, in the angles of which they were fixed, sometimes to the great disfigurement of the room. Within late years the "secret system" of bell-hanging has been introduced, which consists in carrying the wire and cranks in tubes and boxes concealed by the finishings of the walls. The tubes are usually of tinned iron or zinc; but they ought to be either of brass or strong galvanized iron. Zinc is not to be depended upon. In some places it will moulder away. If not soldered, it opens, and the wires work into the joinings of the tube, which stops their movement.

The proper time to commence bell-hanging is when the work is ready for lathing; but it should not be delayed after the rough-cast plastering has commenced. If the work be performed at this

period, it enables the bell-hanger to see his way more clearly, and prevents much cutting away of the plasterers' work afterwards.

The bell-board is usually placed in some conspicuous place, where the bells can be both seen and heard by the attendant. It should be painted white, and each bell should be designated by a letter or number painted on the board.

BELL-METAL. Fr., *Métal des cloches;* Ger., *Glockenmetall;* Ital., *Lega delle campane;* Span., *Metal campanil.*

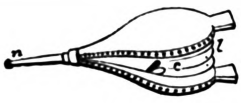
A good average bell-composition is 75 copper, 25 tin; 30 of tin to 100 copper is also a good proportion. Large bells are cast of 80 copper, 6 zinc, 10 tin, 4 lead. A very fine large bell consisted of 71 copper, 26 tin, 2 zinc, and 1 iron. No definite ratios, however, between the metals of which *bell-metal* is composed have as yet been established. See Alloys. Copper. Tin.

BELLOWS. Fr., *Soufflet;* Ger., *Blasebalg;* Ital., *Mantice;* Span., *Fuelle.*

A *bellows* is an instrument, utensil, or machine for propelling air through a tube, for various purposes, as blowing fires, filling the pipes of an organ with wind, and so on. The common bellows is formed of two boards, Fig. 637, with a skin of leather *l* nailed to their edges and hanging loosely between them; thus forming a sort of chamber, which is capable of being enlarged or contracted at pleasure. To the lower board is fixed a metal nozzle *n*, communicating with the wind-chamber; and this board is also furnished with a *clack-valve*, *c*, for the admission of air.

The blast obtained by means of the common bellows is intermittent; and if a continued blast is required, a bellows with a double chamber and an additional valve is necessary. The long shape forge-bellows, Fig. 638, is a bellows of this description, having an extra chamber *a* and an extra valve *b*. The centre-board *d* should be a fixture; the nozzle connected with the upper chamber; the upper board loaded or made of heavy materials, and the lower board moved when in use. The two valves should open alternately.

637.

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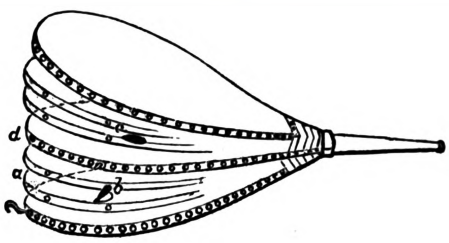


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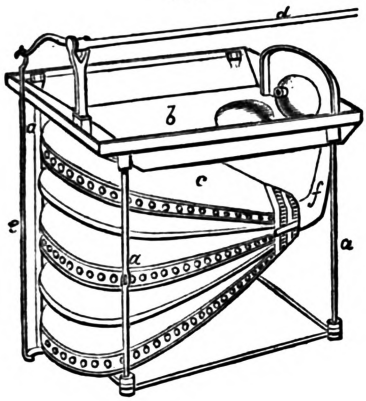
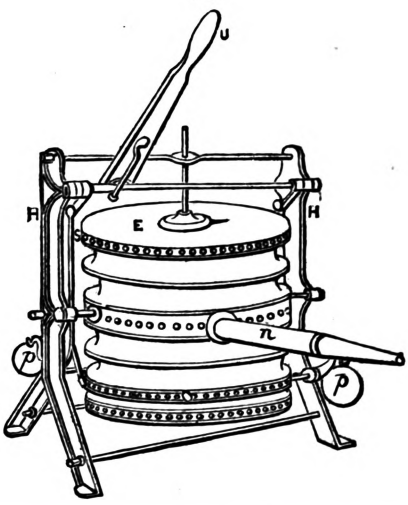



640.




641.

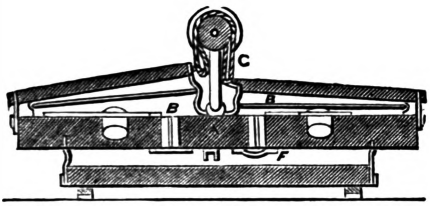


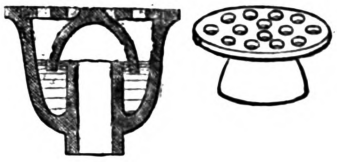

Fig. 639 shows the application of a double-chambered bellows to a portable forge. *a*, *a* are legs supporting the hearth *b*; *c*, the bellows fastened by the centre-board to the legs *a*, and worked by the handle *d* inserted in a hook at the top of the lever *e*. By depressing the handle *d*, the lever *e* lifts the bottom flap of the bellows, which falls by its own weight. The collapsing of the upper flap forces the blast through the pipe *f* to the fire.

Double-blast bellows are frequently made of a circular shape. Fig. 640 shows this arrangement. H is the frame supporting the bellows E, which is worked by the handle U communicating with the lever S. *p*, *p* are weights attached to the lower board *o*, and *n* the nozzle fixed to the centre-board. An arrangement for obtaining a continuous blast of air by the weight and easy movement of a person standing on two bellows, and resting his weight alternately on them, invented by Henry Neumeyer, is shown in Fig. 641. It consists in constructing two bellows B B, connected by a rope C, and fastened to a centre-board A. These bellows rising and falling alternately, by means of valves properly arranged keep the wind-chamber F filled.

BELL-TRAP. Fr., *Pommelle de puisard;* Ger., *Rost im Senkloch;* Ita , *Chiavica a tenuta d'aria.*

A small *stench-trap*, from 3 to 6 in. diam., Fig. 642, usually fixed over the waste-pipe of a sink or other inlet to a drain. The foul air is prevented from rising by an inverted cup or bell, the lips of which dip into a chamber filled with water surrounding the top of the pipe.

642.



The grating to which the bell is attached should never be fastened down, as the opening between the lip and side of the pipe frequently becomes choked, and it is desirable to have the means of freeing it.

The bell should be made to dip deep into the water, to prevent the foul air escaping. Imperfectly-constructed bell-traps, by permitting a communication from the sewer, and so contaminating the air of the dwelling, is the cause of more unhealthiness to the occupants than is commonly supposed. See Drainage and Stench-traps.

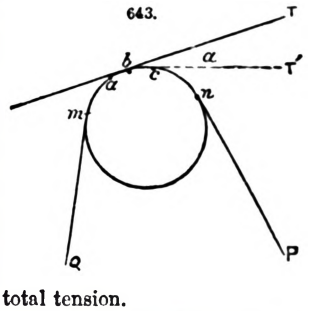
BELTS, Transmission of motion by means of. Fr., *Courroie;* Ger., *Riemen;* Ital., *Coreggia;* Span., *Cintura, Correa.*

There are two theories upon which the transmission of motion, by means of endless belts or cords, are founded. The first, that of M. Prony, relative to the sliding of a cord or belt upon the surface of a drum; the second, that of Poncelet, refers to the variation of tension in the two parts of the belt or cord employed in these transmissions.

Morin proved, by special experiments, the consequences of these two theories; we give a succinct account of the results of these researches.

In explaining the first of these theories, with respect to the slipping of belts upon cylinders, let us consider a belt or cord enveloping a portion of the surface of a cylinder, and acted upon at one end by a power P, and upon the other by a resistance Q, Fig. 643. It is clear that, to produce slipping of the belt, the power P should be equal to the resistance Q, increased by the resistance opposed by the friction of the cord upon the surface of the cylinder. Let us seek to determine this friction.

643.




For this purpose, we consider the two consecutive elements $a\,b$ and $b\,c$ of the belt, and call T the tension of the cord in the element $a\,b$; T′ the tension of the cord in the element $b\,c$. It is evident that the tension T′ exceeds the tension T by an infinitely small quantity $t$, which is precisely the measure of the resistance opposed by the friction; we have then $T' = T + t$; and passing from one element to the other, from the point $n$ of contact of the direction $n$ P, where T = P, to the point $m$ of contact of the direction $m$ Q, where T = Q, the sum of all the increments of tension produced by the friction at the moment of slipping, will give the total tension.

The friction or elementary increase of tension $t$, from the element $a\,b$ to the element $b\,c$, is produced by the pressure resulting from the component of tension T′, normal to the surface, which is T sin. $\alpha$, calling $\alpha$ the infinitely small angle at the intersection of the two elements $a\,b$ and $b\,c$, or simply T $\alpha$, since T differs by an infinitely small quantity from T′, and the sine $\alpha$ from $\alpha$; we have then $t = f.T\alpha = Tf\,\frac{S}{R}$, $f$ being the ratio of the friction to the pressure.

The sum of all these increments of tension, taken from the point $m$, where T = Q, to the point $n$, where T = P, leads, according to analysis which we will presently discuss, to the formula

$$\log. P = \log. Q + 0{\cdot}434 f\,\frac{S}{R}, \text{ or } P = Q \times 2{\cdot}718^{f\frac{S}{R}} = Q\,e^{f\frac{S}{R}},$$

S being the total length embraced by the cord, and R the radius of the circle.

We see by this expression that the tension of the motive power increases from P = Q, answering to S = 0, proportionally to the opening of the angle $\frac{S}{R}$, embraced by the belt, and not to the absolute extent of the arc; which shows, from theoretic considerations, that for an increase of the friction of slipping of cords or belts, it is not essential to enlarge the diameter of the cylinder, but that the proportional part of the circumference to be enclosed should be increased.

The preceding formula relates to the case where the power P is to overcome the resistance Q, and consequently, besides this, to surmount the friction of the cord or belt upon the drum. When, however, as is frequently the case, the force P is to yield to the force or weight Q, for moderating its action, or resisting it altogether, as, for example, in the lowering of goods, the friction acts in favour of the force P, and we have

$$\log. P = \log. Q - 0{\cdot}434 f.\,\frac{S}{R}, \text{ or } P = \frac{Q}{2{\cdot}718^{f\frac{S}{R}}}.$$

Such are the relations which theory indicates between the forces P and Q, the arc of contact, the radius of the drum, and the coefficient of friction. It remains to determine by experiment the correctness of these relations.

*Experiments upon the Slipping of Cords and of Belts upon the Surface of Wooden Drums, and of Cast-iron Pulleys.*—For this purpose Morin made use of three wooden drums, with diameters of 2·741 ft., 1·338 ft., and 0·328 ft., placing them horizontally in a fixed position, so that they could not turn, and over them was passed a belt of black curried leather, nearly new, but having

acquired a certain pliability from previous use. Its breadth was 0·164 ft., and thickness 0·173 ft.; its rigidity seemed so feeble that Morin found himself justified in neglecting it in its ratio to the friction of slipping upon the surface of the drum.

The two strips of the belt hung vertically in equal portions on each side of the drum, and to each of them was attached a scale to receive the weights. The belt weighed 5·06 lbs., each scale 0·5 lb.; consequently, the weight of each strip, of equal length, was, with its plate, 3·03 lbs. The arc embraced was equal to the semi-circumference. At first, equal weights were put in the scales, then gradually was added to one of them the weights necessary to make the belt slide upon the drum.

We see from this, that the tension Q of the ascending strip was equal to 3·03 lbs. plus the weight contained in the corresponding scale, and that the tension P of the descending strip was equal to Q increased by the weight added, over and above the primitive load.

This established, the preceding formula becomes

$$\log. P = \log. Q + 0{\cdot}434\, f\, .\, \frac{S}{R}\, , = \log. Q + 0{\cdot}434\, f \times 3{\cdot}1416,$$

whence we deduce

$$f = \frac{\log. P - \log. Q}{0{\cdot}434 \times 3{\cdot}1416} = \frac{\log. P - \log. Q}{1{\cdot}363}\, .$$

By introducing in this formula the values of P and Q furnished by experiments, we are enabled to calculate the different values of the ratio $f$ of the friction to the pressure, and to be assured that they confirm the theoretic consequences which we have unfolded.

The two following Tables contain the results of the experiments:—

EXPERIMENTS UPON THE FRICTION OF BELTS UPON WOOD DRUMS.

| Width of Belt. | Condition of the Belt. | Diameter of Drum. | Length of Arc embraced. | Tension of the Part. | | Ratio of Friction to Pressure, $f$. |
|---|---|---|---|---|---|---|
| | | | | Rising, Q. | Falling, P. | |
| ft. | | ft. | ft. | lbs. | lbs. | |
| 0·164 | Dry, somewhat oily | 2·741 | 4·306 | 14·060 | 66·992 | 0·497 |
| | | | | 14·060 | 64·786 | 0·486 |
| | | | | 14·060 | 64·786 | 0·492 |
| | | | | 36·114 | 167·341 | 0·488 |
| | | | | 36·114 | 153·336 | 0·460 |
| | | | | 36·114 | 151·461 | 0·458 |
| | | | | 25·087 | 111·102 | 0·473 |
| | | | | 25·087 | 95·603 | 0·426 |
| | | | | | Mean .. | 0·472 |
| 0·164 | Dry, somewhat oily | 1·338 | 2·099 | 14·060 | 63·683 | 0·472 |
| | | | | 14·060 | 69·197 | 0·458 |
| | | | | 14·060 | 63·242 | 0·507 |
| | | | | 36·114 | 140·875 | 0·479 |
| | | | | 36·114 | 140·875 | 0·433 |
| | | | | | Mean .. | 0·462 |
| 0·164 | Dry, somewhat oily | 0·328 | 0·514 | 14·060 | 73·608 | 0·526 |
| | | | | 14·060 | 75·813 | 0·541 |
| | | | | 25·087 | 91·252 | 0·411 |
| | | | | 25·087 | 98·975 | 0·438 |
| | | | | 25·087 | 94·560 | 0·422 |
| | | | | 36·114 | 161·827 | 0·477 |
| | | | | 36·114 | 168·576 | 0·490 |
| | | | | | Mean .. | 0·472 |
| 0·091 | Very dry and rough. | 2·741 | 4·306 | 11·911 | 71·458 | 0·570 |
| | | | | 11·911 | 72·560 | 0·575 |
| | | | | 22·938 | 114·465 | 0·512 |
| | | | | 22·938 | 104·541 | 0·483 |
| | | | | 33·965 | 137·622 | 0·446 |
| | | | | 33·965 | 136·519 | 0·443 |
| | | | | | Mean .. | ·504 |
| | | | | | General Mean .. .. | 0·477 |

EXPERIMENTS UPON THE FRICTION OF BELTS OF CURRIED LEATHER UPON CAST-IRON PULLEYS.

| Breadth of Belt. | State of the Belt. | Diameter of the Pulley. | Arc embraced S. | Tension of Strip. Ascending Q. | Tension of Strip. Descending P. | Ratio of Friction to Pressure $f$. | Remarks. |
|---|---|---|---|---|---|---|---|
| ft. | | ft. | ft. | lbs. | lbs. | | |
| 0·164 | Dry, a little unctuous | 2·000 | 3·143 | 14·060 | 29·719 | 0·338 | This belt was old, having been used a long time in a spinning-mill. The pulley was not turned. |
| | | | | 14·060 | 36·996 | 0·308 | |
| | | | | 14·060 | 34·791 | 0·288 | |
| | | | | 25·087 | 64·566 | 0·301 | |
| | | | | 36·114 | 89·047 | 0·282 | |
| | | | | 36·114 | 82·436 | 0·262 | |
| | | | | | Mean.. | 0·279 | |
| 0·164 | Dry, a little unctuous | 2·000 | 3·143 | 14·060 | 35·286 | 0·300 | This belt was new. The pulley was not turned. |
| | | | | 25·087 | 61·478 | 0·285 | |
| | | | | 25·087 | 57·067 | 0·271 | |
| | | | | 36·114 | 80·224 | 0·254 | |
| | | | | 36·114 | 80·224 | 0·254 | |
| | | | | 58·170 | 160·724 | 0·323 | |
| | | | | | Mean.. | 0·281 | |
| 0·164 | Dry, a little unctuous | 0·361 | 0·566 | 14·060 | 31·704 | 0·259 | The pulley was turned; its width was only ·098 ft., and so reduced the slipping part of the belt to ·098 ft. |
| | | | | 14·060 | 40·525 | 0·336 | |
| | | | | 25·087 | 59·273 | 0·273 | |
| | | | | 25·087 | 68·095 | 0·318 | |
| | | | | 36·114 | 81·328 | 0·259 | |
| | | | | 36·114 | 81·328 | 0·259 | |
| | | | | | Mean.. | 0·284 | |
| 0·164 | Moistened with water | 2·000 | 3·143 | 25·087 | 68·095 | 0·317 | |
| | | | | 14·060 | 43·834 | 0·361 | |
| | | | | 14·060 | 43·834 | 0·361 | |
| | | | | 36·114 | 114·410 | 0·366 | |
| | | | | 36·114 | 127·643 | 0·401 | |
| | | | | 47·142 | 199·321 | 0·458 | |
| | | | | | Mean.. | 0·377 | |

We see by the results of these experiments, in which the arc of contact varied in the ratio of 8·3 to 1 nearly, and where the tension has reached very nearly the limits assigned to the belts of machinery, that the value of the ratio $f$, of friction to the pressure, remained very nearly constant.

The three first series of the first Table fully confirm the theoretic considerations. The fourth series relates to a belt quite new, and very stiff, and to this we attribute the small increase presented by it in the mean value. This belt having, moreover, only a width of ·091 ft., or about the half of the preceding, we see that this last series confirms, as to belts, the law of the independence of surface.

In the experiments of the second Table, the extent of arc embraced varied in the ratio of 6 to 1, the breadth of the belt pressed against the pulley in that of 2 to 1, the tension from 1 to 3 and from 1 to 6, and still the value of the ratio $f$, of friction to the pressure, remained sensibly constant, and equal in the mean, for the dry belt and dry pulleys, $f = 0{\cdot}282$. When the pulley was moistened with water we had $f = 0{\cdot}377$.

*Conclusions.*—In considering the results of these two series of experiments upon the friction of belts upon wooden drums and cast-iron pulleys, we see that we are justified in admitting that the ratio of the resistance to the pressure is:—

1st. Independent of the width of the belt and of the developed length of the arc embraced, or of the diameters of the drums, or, what amounts to the same, are independent of the surface of contact.

2nd. Proportional to the angle subtended by the belt at the surface of the drum.

3rd. Proportional to the logarithm of the ratio of the tension of the strips, and expressed by the formula

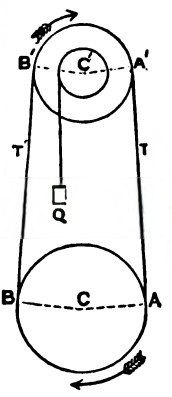
$$f = \frac{\log.\left(\frac{P}{Q}\right)}{1{\cdot}363}.$$

*Experiments upon the Variation of the Tension of Endless Cords or Belts used in Transmitting Motion.*—We pass now to an experimental proof of the theory given by M. Poncelet, upon the transmission of motion by endless cords or belts, and will first give a description of its nature.

When a cord or belt surrounds two pulleys or drums, between which it is designed to maintain a conjoint motion, care is taken to give it a sufficient tension, which is usually determined by trial, but which it would be best to calculate, as we shall see hereafter. The *primitive* tension is, at the commencement, the same for both parts of the belt; and this equality, established in repose, is only destroyed by the friction of the axles, which may act in either direction, according to that of the motion of the pulleys.

Let us examine how this motion is transmitted in such a system. Let C be the motive drum; C′ the driven drum; $T_1$ the primitive tension common to the parts A A′ and B B′ of the belt, from the moment when the drum C begins to turn until it commences to turn the drum C′.

644.




The point A of primitive contact of the part A A′ advances, in separating from the point A′, in the direction of the arrow; the strip A A′ is stretched, and its tension increased by a quantity proportional to this elongation, according to a general law proved by experiment upon traction.—(See Lessons upon 'Résistance des Matériaux.') At the same time, the point B of contact of the part B B′ approaches by the same quantity towards the point B′, so that the portion B B′ is diminished by a quantity equal to the increase of that of A A′. If, then, we call T the tension of the driving portion A A′, at the instant of its being put in motion, T′ the tension of the driven part B B′, $t$ the quantity by which the primitive tension $T_1$ is increased in the portion A A′, and diminished in the part B B′, we shall have $T = T_1 + t$, and $T' = T_1 - t$, and consequently $T + T' = 2T_1$. Then, at any instant, the sum of the two tensions T and T′ is constant and double the primitive tension.

Now it is evident that in respect to the driven drum C′ the motive power is the tension T, and that the tension T′ acts as a resistance with the same lever arm, so that the motion is only produced and maintained by the excess T − T′ of the first over the second of these tensions.

If the machine is, for example, designed to raise a weight Q acting at the circumference of an axle with a radius R′, it is easy to see, according to the theory of moments, that at any instant of a uniform motion of the machine we must have the relation

$$(T - T')\,R = Q\,R' + f\,N\,r,$$

N being the pressure upon the journals, and $r$ their radius.

The pressure is easily determined; for calling $a$ the angle formed by the directions A A′ and B B′ of the belts with the line of the centres C C′, M the weight of the drum, we see immediately that $N = \sqrt{[M + Q + (T - T')\sin. a]^2 + (T + T')\cos.^2 a}$, an expression which, according to the algebraic theorem of M. Poncelet, has for its value a fraction equal to $\frac{1}{25}$ nearly, when the first term under the radical is greater than the second, $N = 0{\cdot}96\,[M + Q + (T - T')\sin. a] + 0{\cdot}4\,(T + T')\cos. a$. This value of N being introduced into the formula for equality of moments, we have a relation containing only the values of the resistance Q and of the tensions. But as it may be somewhat complicated for application, observing that in most cases the influence of the tensions T and T′ upon the frictions will be so small that it may be neglected, at least in a first approximation, we proceed as follows:

First, neglecting the influence of the tensions upon the friction, we have simply, in the actual case, N = M + Q, and consequently $(T - T')\,R = Q\,R' + f\,(M + Q)\,r$, whence we deduce

$$T - T' = \frac{Q\,(R' + fr) + f\,.\,M\,r}{R} = Q,$$

which furnishes a first value for the difference of tensions, which is the motive power of the apparatus.

But this is not sufficient to make known these tensions, and it is necessary to determine the primitive tension T′, so that in no case the belt may slip.

According to the theory of M. Prony, we have, at the instant of slipping, between the tension, T and T′ the relation $T = T' \times 2{\cdot}718 + f\,\frac{S}{R}\,T' = K\,T'$, the number K being a quantity depending upon the nature and condition of the surfaces of contact, as well as upon the angle $\frac{S}{R}$ embraced by the belts upon the drum C′. These quantities are known, and we may in each case calculate the value of K by this formula, or take it from the following Table, which answers to nearly all the cases in practice.

By means of this Table, we shall have then the value of $T = K\,T'$, and consequently $T - T' = (K - 1)\,T' = Q$, Q representing the greatest value which the difference of tensions should attain to overcome the useful and passive resistances.

From this relation we may derive the smallest tension to be allowed to the driven portion of the belt to prevent its slipping: we thus have $T' = \frac{Q}{K - 1}$.

We should increase this value by $\frac{1}{10}$ at least, to free it from all hazard of accidental circumstances, and to restore the account of the influence of the tensions upon the friction, which was neglected. This established, we have $T = Q + \frac{Q}{K - 1}$, and consequently

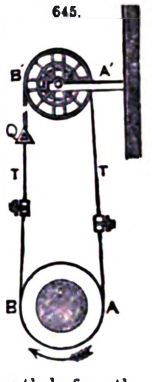
$$T_1 = \frac{T + T'}{2} = \frac{1}{2}\,\frac{K + 1}{K - 1}\,Q.$$

All the circumstances of the transmission of motion will then be determined.

If these first values of T, T', and $T_1$ are not considered as sufficiently correct, we may obtain a nearer approximation by introducing them in the value of the pressure N, and thus deduce a more exact value of Q, which will serve to calculate anew T', then T and $T_1$.

| Ratio of the Arc embraced to the Circumference. | Value of the Ratio K. | | | | | |
|---|---|---|---|---|---|---|
| | New Belts upon Wooden Drums. | Belts in usual Condition. | | Moistened Belts upon Cast-iron Pulleys. | Cords upon Wooden Drums or Axles. | |
| | | Upon Wooden Drums. | Upon Cast-iron Pulleys. | | Rough. | Smooth. |
| 0·20 | 1·87 | 1·80 | 1·42 | 1·61 | 1·87 | 1·51 |
| 0·30 | 2·57 | 2·43 | 1·69 | 2·05 | 2·57 | 1·86 |
| 0·40 | 3·51 | 3·26 | 2·02 | 2·60 | 3·51 | 2·29 |
| 0·50 | 4·81 | 4·38 | 2·41 | 3·30 | 4·81 | 2·82 |
| 0·60 | 6·59 | 5·88 | 2·87 | 4·19 | 6·58 | 3·47 |
| 0·70 | 9·00 | 7·90 | 3·43 | 5·32 | 9·01 | 4·27 |
| 0·80 | 12·34 | 10·62 | 4·09 | 6·75 | 12·34 | 5·25 |
| 0·90 | 16·90 | 14·27 | 4·87 | 8·57 | 16·90 | 6·46 |
| 1·00 | 23·14 | 19·16 | 5·81 | 10·89 | 23·90 | 7·95 |
| 1·50 | .. | .. | .. | .. | 111·31 | 22·42 |
| 2·00 | .. | .. | .. | .. | 535·47 | 63·23 |
| 2·50 | .. | .. | .. | .. | 2574·80 | 178·52 |

*Experiments upon the Variations of Tensions of Endless Belts employed for the Transmission of Motion.*—To verify by experiment the exactness of these considerations, Morin placed vertically above the axis of a hydraulic wheel, and of a pulley mounted upon its axle, a cylindrical oak drum, 2·74 ft. in diameter, and whose axis was 9·84 ft. from that of the wheel. Around this drum A'B', and the pulley A B, was passed a belt which, instead of being in one piece, was in two parts, joined at each end by a dynamometer, with a plate and style, of a force of 441 lbs. Moreover, these *dynamometers* were easily secured in positions such that that of the descending portion of the belt was near the upper drum, and that of the ascending near the lower drum. Thus the belt could be moved over a space of 6·56 ft. without the risk of the instruments being involved with the drums.




A thread wound several times around the circumference of one of the grooves of the plate of each of the dynamometers, and attached by the other end to a fixed point, caused the plate to turn when the apparatus was in motion, and the paper with which the plate was covered received thus the trace of the style of the dynamometer.

The belt being passed over the two drums, the tensions of the parts were varied at will in either direction, by suspending at the circumference of the upper drum a plate Q charged with weights. As to the primitive tension, it was increased by bringing nearer together the ends of the belt, or in diminishing its length before the experiment.

The apparatus being thus prepared for observations, before loading the plate Q, we traced the circles of flexure of each of the dynamometers, so as to have the tensions of the belt at rest, and to obtain by their sum the double of the primitive tension $T_1$. We may conceive that these two tensions can never be quite equal; but that is not important, inasmuch as we have to deal only with their sum.

This obtained, we load the plate with a weight which, being suspended upon the circumference by a cord of a diameter equal to the thickness of the belt, has the same lever arm as the tensions. That part of the belt opposed to this weight is stretched, and the part on the same side is slackened, and we trace the new curves of the flexure of the dynamometers.

For the same primitive tension we may make a series of experiments up to the motive weight, under the action of which the belt slides upon either drum.

In these experiments facilities were afforded for allowing the two drums to turn a certain amount under the action of the tensions, so that we could realize the three cases in practice, to wit, that of the variation of tensions before motion was produced, that of the variation during motion, and finally, that of the slipping.

The belt used in these experiments was very pliable, soft, and little liable to be polished in slipping. In calculating the ratio of the friction to the pressure for this belt, by means of experiments 3, 13, and 19, we find respectively $f = 0{\cdot}578$, $f = 0{\cdot}596$, and $f = 0{\cdot}544$, the mean being $f = 0{\cdot}573$.

*Remarks upon the Results contained in the following Table.*—We see that the first line of each series corresponds to the case where there was no additional weight, and where each portion of the belt took the primitive pressure corresponding to the distance apart of the axes. As the weight suspended from the drum was increased, the tension of one of the strips was increased, and that of the other was diminished; but so that their sum remained constant, as is shown by the fifth column of the Table.

These results, which completely confirm the theory of M. Poncelet, being relative to tensions whose sum reaches 198 lbs. and more, where the greatest rise as high as 169 lbs., and the smallest fall as low as 11 lbs., comprise nearly all the cases in practice, and show that this theory may with safety be applied to the calculation of transmission of motion by belts.

EXPERIMENTS UPON THE VARIATION OF THE TENSIONS OF ENDLESS BELTS EMPLOYED IN TRANSMITTING MOTION BY PULLEYS OR DRUMS.

| Number of Experiment. | Weight suspended at the Circumference. | Tension of the Part. | | Sum of the Tensions, $T + T' = T_1$. | Remarks. |
|---|---|---|---|---|---|
| | | Rising or stretched, T. | Descending or slackened, T'. | | |
| | lbs. | lbs. | lbs. | lbs. | |
| 1 | 0·00 | 38·57 | 32·84 | 71·41 | |
| 2 | 44·61 | 60·07 | 12·84 | 72·91 | |
| 3 | 59·55 | 63·14 | 10·19 | 73·33 | The belt slipped. |
| 4 | 0·00 | 64·86 | 57·41 | 122·27 | |
| 5 | 22·56 | 75·09 | 46·82 | 121·90 | |
| 6 | 44·61 | 84·51 | 36·26 | 120·77 | The dynamometers moved about 3·28 ft. |
| 7 | 66·67 | 97·96 | 24·17 | 122·13 | |
| 8 | 97·54 | 109·92 | 20·76 | 130·67 | |
| 9 | 0·00 | 73·73 | 62·32 | 136·05 | Ditto ditto. |
| 10 | 55·64 | 99·00 | 41·53 | 140·53 | |
| 11 | 110·78 | 117·77 | 20·38 | 138·15 | |
| 12 | 0·00 | 66·91 | 57·94 | 124·85 | |
| 13 | 115·19 | 103·78 | 15·86 | 119·64 | The belt slipped. |
| 14 | 0·00 | 107·53 | 98·91 | 206·44 | |
| 15 | 55·64 | 130·05 | 70·26 | 200·31 | |
| 16 | 110·78 | 157·02 | 47·57 | 204·59 | |
| 17 | 0·00 | 97·24 | 88·75 | 185·99 | |
| 18 | 110·78 | 154·29 | 40·78 | 195·07 | |
| 19 | 174·23 | 170·67 | 43·42 | 214·09 | Ditto ditto. |
| 20 | 0·00 | 86·72 | 71·34 | 158·06 | |
| 21 | 88·72 | 134·84 | 44·17 | 179·01* | |

* Besides the load Q, there was suspended to the main circumference of the floats of the wheel, at 6·05 ft. from the axis, a weight of 22·56 lbs., which broke the equilibrium.

In conclusion, we would add that belts designed for continuous service may be made to bear a tension of 0·551 lb. per ·0000107 sq. ft., or ·00155 sq. in. of section, which enables us to determine their breadth according to the thickness.

We give, from the 'Journal of the Franklin Institute' (1868), an account of the experiments and comparisons of Robert Briggs and H. R. Towne, relative to the transmission of force by belts and pulleys. The results so independently obtained by these investigators will, we have no doubt, be useful to those engaged in the construction and working of machinery.

R. Briggs observes:—"There are few mechanical engineers who have not been frequently in want of tabular information or readily applicable formulas, upon which they could place reliance, giving the power which, under given conditions and velocity, is transmitted by belts without unusual strain or wear. The formula of the belt or brake is well known and simple; and it is only necessary to acknowledge and adopt a value for the coefficient of friction (or of adhesion, which is perhaps the better term), to allow this formula to be applied in daily use. And this coefficient of friction has been carefully established by the experiments of General Morin and M. Prony, and has been made available to English and American engineers, by the translation of Bennett. It must be remarked that there are some mistakes in the text of Bennett's translation, which will lead to serious errors, unless read by a careful investigator.

"With every point needed, therefore, at the command of the engineer, it is somewhat surprising that a more extensive publication and general use of the data has not followed.

"But notwithstanding the existence of this correct mathematical and experimental information, the numerous tables which have been given by mechanical engineers appear to have had only that kind of practical basis which has come from guessing that an engine or a machine, either the driving or the driven, with a belt of given width, was producing or requiring some quantity of power, which might be expressed in terms generally without any stated arc of contact."

The terms referred to are vulgarly called foot-pounds, but should be nominated *units of work*. See PRINCIPLE OF WORK.

"Three rules given by practical mechanics vary so much, as to give as bases for estimate (without regard to arc of contact) 0·76 horse-power, 0·93 horse-power, and 1·75 horse-power, respectively, for the power of a belt 1 in. wide running 1000 ft. per minute.

"It was the requirement to know the exact useful effect of a novel disposition involving an unusual small arc of contact of the belt upon the pulley, where much embarrassment would result if the application proved itself unsatisfactory, that led to the present inquiry. As the writer was not able to give the time demanded for making such experiments as would establish the practical coefficient of adhesion, he, Briggs, suggested what was desired to H. R. Towne; and the numerous experiments, of which he gives the accompanying report, are the result of the labour and care of H. R. Towne.

"It was not until after the experiments were completed," says H. R. Towne, "that either he or R. Briggs knew of the publication of M. Prony or General Morin, although Bennett's translation rested upon the shelves of the writer's library; but, aside from the gratification which we feel at the corroboration, we think the reader of this article will be pleased to know that our data is founded upon the ordinary pulleys and belts of the workshop, and our experiments were not impaired by any niceties which common workmen would not apply.

"Even the crudeness of our experimental apparatus, and the general not over-exact method adopted, will serve to demonstrate to the minds of practical men the possibility of relying upon figures which have been established so nearly in accordance with the customs of the workshop."

We have before shown that $\frac{T_1}{T_2} = \epsilon^{f\frac{l}{r}}$, or, $\frac{Q}{P} = \epsilon^{f\frac{l}{r}}$, where $\epsilon$ is the base of hyperbolic logarithms; $T_1$ = the tension of the belt on the tight side; $T_2$ = the tension of the belt on the loose side; $f$ = the coefficient of friction; $r$ = radius of pulley; and $l$ = the length of the arc of contact. We can further transform this equation, by substituting the ratio of the angle in degrees for the length of contact on the arc, compared to the radius, $\epsilon = 2{\cdot}718281828$.

Thus $\frac{2r\pi}{360}$ = arc of 1°, let $l = a\left(\frac{2r\pi}{360}\right)$ $\therefore \frac{T_1}{T_2} = \epsilon^{f\frac{2\pi a}{360}}$, and taking the numerical values of $\epsilon$, $\pi$, and dividing out the 360, $\therefore \frac{T_1}{T_2} = 2{\cdot}718^{0{\cdot}017456 f a}$

$$\therefore \log.\left(\frac{T_1}{T_2}\right) = 0{\cdot}4343\ (0{\cdot}017456 f a), \qquad [1]$$

$$\therefore \log. T_1 - \log. T_2 = 0{\cdot}00758 f a$$

$$\therefore \frac{T_1}{T_2} = 10.^{0{\cdot}00758 f a}, \qquad [2]$$

$$\therefore f = \frac{\log.\left(\frac{T_1}{T_2}\right)}{0{\cdot}00758\, a} \qquad [3]$$

As we assumed, $P = T_1 - T_2$. $\therefore T_2 = T_1 - P$, which inserting in equation [2]

$$\therefore \frac{T_1}{T_1 - P} = 10^{0{\cdot}00758 f a}$$

$$\therefore P\left(10^{0{\cdot}00758 f a}\right) = T_1\left(10^{0{\cdot}00758 f a}\right) - T_1$$

$$\therefore P = T_1\left(1 - 10^{-0{\cdot}00758 f a}\right) \qquad [4]$$

The third equation is the one to which we would now call attention. By it, for any given values for the ratio $\frac{T_1}{T_2}$, we can determine the coefficient of friction, when, by experiment, we have fixed the greatest difference of the two strains without slipping on a pulley with a given arc (measured by $a$) of contact.

We would here, says the experimenter, make a very important observation, which forms the key of the whole system of transmission of force by belts. In practice, *all belts are worked at the maximum coefficient of friction.* A belt may, when new or newly tightened, work under heavy strain, and with a small coefficient of friction called into action; but in process of time it becomes loose, and it is never tightened again until the effort to perform its task is greater than the value of the coefficient with a given tension of belt and the belt-slips. We, says Briggs, run our belts as slack as possible, so long as they continue to drive.

It has been shown that the value of $T_1 + T_2$, or the sum of the strains upon the two sides of a belt (loose and tight), is a constant quantity—that is, when a belt is performing work it will become loose on the one side to the exact amount that it is strained on the other, and when at rest, not transmitting force, the tensions will become equal, and their sum be the same as before. It is manifest that the limit of the strength of a belt is found in the maximum tension $T_1$ and that this strength being known, the effective pull (P) is further limited with any given arc of contact by the value $f$, of the coefficient of friction.

The discussion has so far been limited to the pull exerted by a belt; when we would include the power which belts will transmit, we have only to multiply the pull by some given or assumed velocity, to transform our equations into work performed.

By means of the third equation, we will now deduce a value for the coefficient of friction as given by the experiments.

All the experiments were with the arc of contact = 180° = $a$, which, substituting $f = \frac{\log.\frac{T_1}{T_2}}{1{\cdot}3644}$, and the result of 168 separate experiments has given, under tensions of T, from 7 to 110 lbs. to an inch of width of belt, $\frac{T_1}{T_2} = 6{\cdot}294$. $\therefore f = \frac{\log. 6{\cdot}294}{1{\cdot}3644} = 0{\cdot}5833$. Bennett's Morin, page 306, ¶ 253, gives $f = 0{\cdot}573$.

In this case $T_1$ has in all cases been so much in excess of $T_2$, as to slip the belt at a defined, slow, but not accelerating, motion.

From an examination of the report of the experiments, we think the reader will coincide with our conclusion that $\frac{6}{10}$ of this value of $\frac{T_1}{T_2}$ can be taken as a suitable basis for the working friction or adhesion which will cover the contingencies of condition of the atmosphere as regards temperature and moisture; or $\frac{T_1}{T_2} = 3{\cdot}7764$ (maximum practical value) $\therefore f = \frac{\log. 3{\cdot}776}{1{\cdot}3644} = 0{\cdot}42292.$

It should be noted that the experiments were made without any appreciable velocity of belt, and throughout this paper no regard has been paid to the effect of velocity or of the dimensions of the pulleys upon the value of the coefficient of friction.

For pulleys less than 12 in. diameter (with the belts of the ordinary thickness of about $\frac{3}{16}$ths in.), and for velocities exceeding about 1000 ft. a minute, allowance must be made for the rigidity of the belt in the one case, and for the *interposition of air between the pulley and the belt* in the other. At high speeds, say 3000 ft. velocity of belt a minute, the want of contact can be seen, sometimes, to the extent of one-third the arc encompassed by the belt. Briggs has proposed to place a deflector or stripper near the belt, to take off the stratum of air moving with it, but has never tried the experiment, although he has little doubt of its giving some advantage.

The experiments further show that 200 lbs. to an inch of width of belt is the maximum strength of the weakest part—that is, of the lace-holes. Taking this, with a factor of safety at one-third, we have the working strength of the belt, or the practical value for $T_1 = 66\frac{2}{3}$ lbs. Bennett's Morin, page 306, ¶ 253, gives 55·1 lbs. the inch of width as admissible. In the case when belts are spliced instead of laced, a great increase of strength has been shown, the experiments giving 380 lbs. to an inch of width, or 125 lbs. safe working strength.

If we insert these values of $f$ and $T_1$ in [4],

$$\therefore P = 66\tfrac{2}{3}\left(1 - 10^{-0{\cdot}0078 \times 0{\cdot}42292\,\alpha}\right)$$

$$\therefore P = 66\tfrac{2}{3}\left(1 - 10^{-0{\cdot}003206\,\alpha}\right) \qquad [5]$$

This equation [5] is the really important one in practice, and by means of logarithms can be solved for any values of $\alpha°$ readily; but as some of those who may wish to use it may not be at once prepared to use the logarithmic notation, from want of use or practice, we give an example. Suppose we take an angle of 90°, the negative exponent then becomes $-0{\cdot}003206 \times 90 = -0{\cdot}28854$; subtracting this from 1, we have $-1{\cdot}71146$. This term thus becomes $10^{-1{\cdot}71146}$. Now this expression is only the notation for anti-logarithm $-1{\cdot}71146$, or in words the number for which $-1{\cdot}71146$ is the logarithm. Logarithmic tables give this number $= 0{\cdot}51505$, and the equation

$$P = 66\tfrac{2}{3}\left(1-10^{-0{\cdot}003206 \times 90}\right) = 66\tfrac{2}{3}\left(1-10^{-1{\cdot}71146}\right) = 66\tfrac{2}{3}\,(1-0{\cdot}51505) = 66\tfrac{2}{3} \times 0{\cdot}48495.$$

$$\therefore P = 32{\cdot}33.$$

The largest possible angle for an open belt, without a carrier or tightener, is 180°, as upon either the driving or the driven pulley this cannot be exceeded; but for crossed, or carried, or tightened belts, the angle may be as large as 270°.

Briggs and Towne give the following Table of results for different arcs of contact (corresponding to $\alpha°$) within the usual limits of practice.

TABLE I.—STRAIN TRANSMITTED BY BELTS OF ONE INCH WIDTH UPON PULLEYS WHEN THE ARCS OF CONTACT VARY AS THE ANGLES OF

| 90° | 100° | 110° | 120° | 135° | 150° | 180° | 210° | 240° | 270° |
|---|---|---|---|---|---|---|---|---|---|
| lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| 32·33 | 34·80 | 37·07 | 39·18 | 42·06 | 44·64 | 49·01 | 52·52 | 55·33 | 57·58 |

If we suppose the pulley to be 1 ft. in diameter, and to run some number, N, of revolutions a minute, we have the power transmitted $= N\,\pi\,P$.

And we give the following Table for different arcs of contact (corresponding to $\alpha°$) within the usual limits of practice.

TABLE II.—POWER TRANSMITTED BY BELTS ON PULLEYS ONE FOOT IN DIAMETER ONE REVOLUTION A MINUTE. ARCS OF CONTACT OF BELTS UPON PULLEYS CORRESPONDING TO THE ANGLES:

| Inches of Width of Belt. | 90° | 100° | 110° | 120° | 135° | 150° | 180° | 210° | 240° | 270° |
|---|---|---|---|---|---|---|---|---|---|---|
| | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. | foot-lbs. |
| 1 | 102 | 109 | 116 | 123 | 132 | 140 | 154 | 165 | 174 | 181 |
| 2 | 203 | 219 | 233 | 246 | 264 | 280 | 308 | 330 | 348 | 361 |
| 3 | 305 | 328 | 349 | 369 | 396 | 420 | 462 | 495 | 521 | 542 |
| 4 | 406 | 437 | 466 | 492 | 528 | 560 | 616 | 660 | 695 | 723 |
| 5 | 508 | 547 | 582 | 615 | 660 | 701 | 770 | 825 | 869 | 904 |
| 6 | 609 | 656 | 699 | 738 | 792 | 841 | 924 | 990 | 1043 | 1084 |
| 7 | 711 | 766 | 815 | 861 | 924 | 982 | 1078 | 1155 | 1217 | 1265 |
| 8 | 813 | 875 | 932 | 985 | 1056 | 1122 | 1232 | 1320 | 1391 | 1446 |
| 9 | 914 | 984 | 1048 | 1108 | 1188 | 1262 | 1386 | 1485 | 1564 | 1626 |
| 10 | 1016 | 1094 | 1165 | 1231 | 1321 | 1402 | 1540 | 1650 | 1738 | 1807 |

The application of Table II. to any given cases of known angle of the arc of contact, width of belt in inches, diameter of pulley in feet, and number of revolutions, is simply to take the figures from the Table for the first two, and multiply by the two succeeding conditions, to obtain the foot-pounds of power transmitted.

These experimenters take the following examples:—1st. Schenck (of New York) found an 18-in. wide belt running 2000 ft. a minute, the pulleys being 16 ft. to 6 ft., would give 40 horse-power, with ample margin (one-fourth).

If we take the distance from centre of the 16-ft. pulley to that of the 6-ft. to be 25 ft. (about the usual way of placing the fly-wheel pulley of an engine in regard to the main line of shafting), we have the arc of contact subtending about 153°. From Table I. the strain transmissible is 45·1 lbs. × 18 × 2000 = 1,623,600 foot-pounds or units of work = 49·2 HP.

2nd. William B. Le Van (of Philadelphia) found by indicator that an 18-in. wide belt running 1800 revolutions a minute, the pulleys being 16 ft. and 5 ft., respectively, transmitted 43 HP., with maximum power transmissible unknown. If we take the centre's distance, as before, at 25 ft., we have the arc of contact subtending about 150°.

From Table I. we derive 44·64 lbs. as the strain transmissible × 18 × 1800 = 1,446,336 foot-pounds = 43·83 HP. The same authority found by indicator that a 7-in. wide belt over two 2-ft. 6-in. pulleys, 11 ft. centre to centre (horizontal), moving 942 ft. a minute, gave 8 HP. From Table I., for 180° angle, we take 49·01 × 7 × 942 = 323,172 foot-pounds = 9·79 HP. This belt was stated to be very tight.

3rd. A. Alexander ('Engineer,' March 30, 1860) gives a rule that a 1-in. belt will, at 1000 ft. velocity, transmit 1¾ HP.

If we take the contact at 180° from Table I., 49·01 × 1000 = 49,000 foot-pounds, we have only 1½ HP.

4th. William Barbour (same journal, March 23, 1860) gives as the power a 1-in. belt will transmit with 1000 ft. velocity = 0·927 HP., when we derive with 180° angle from our Tables = 1½ HP.

5th. A. B. Ex (same journal, April 6, 1860) gives a rule

$$\frac{\text{diameter in inches} \times \text{revolutions a minute} \times \text{breadth in inches}}{5000} = \text{N HP},$$

ratio of pulleys not to exceed 5 to 1. Changing this rule to

$$\frac{\text{diameter in feet} \times \text{revolutions a minute} \times \text{width in inches}}{5000 \div 12 \div 33{,}000} = \text{N foot-pounds.}$$

$$\therefore \frac{\text{Diameter in feet} \times \text{revolutions a minute} \times \text{width in inches}}{0{\cdot}01263} = \text{N foot-pounds.}$$

$\therefore$ 79·2 × diameter in feet × revolutions a minute × width in inches = N foot-pounds.

From Table II. the angle of 120° gives 123 in place of 79·2, and it would appear this authority adopts about ⅔ the effect we take.

6th. W. Fairbairn gives ('Mills and Mill Work,' Part II., page 4) a table of approximate width of leather straps in inches necessary to transmit any number of horse-power; the velocity of the belt being taken at 25 to 30 ft. a second (1500 to 1800 a minute), 1-foot pulley, 3·6 in. wide, gives 1 HP.

Assume 1650 ft. a minute, contact 180°, we have from Table I., 1650 × 49·01 × 3·6 × 1 = 29,112 foot-pounds = 0·87 HP.

7th. Rankine gives ('Rules and Tables,' page 241) 0·15 as the coefficient of friction, probably applicable to the adhesion of belts on pulleys to be used with his formulas in estimating the power transmitted. Neither experiments nor practice give so small a coefficient as this.

We, says Briggs, could multiply authorities on these points, but think the corroboration of those we quote with our Tables sufficient to establish our experimental and estimated coefficient of friction, $f = 0{\cdot}423$, as a proper practical basis.

These experimenters give the two following cases, not only to show the application of the formula 5, but as matters of some interest.

In the construction of one of the forms of centrifugal machines for removing water from saturated substances, the main or basket spindle is driven by cone-formed pulleys, one of which, being covered with leather, impels the other by simple contact.

In the particular instance taken, the iron pulley on the spindle was 6 in. largest diameter, and the leather-covered driving-pulley was 12 in. largest diameter; the length of cones on the face was 4 in., this last dimension corresponding to width of belt in other cases. By covering the leathered pulley with red-lead, we were able to procure an *impression* on the iron pulley, showing the width of the surfaces of contact when the pulleys were compressed together with the force generally applied when the machine was at work. This width was, at the largest diameters, almost exactly ¼ in. From the nature of the two convex surfaces compressing the leather between them, the actual surface of efficient contact cannot be taken at over half this width. (The slight error in estimating this contact as straight lines in place of circular arcs may be neglected.) This gives the angle subtended by the arc of contact on the iron pulley = 2½°, taking equation [5]. $P = 66\frac{2}{3}\left(1 - 10^{-0{\cdot}003206\,\alpha^\circ}\right) = 66\frac{2}{3}\left(1 - 10^{-0{\cdot}008015}\right) = 66\frac{2}{3}\left(1 - 10^{-1{\cdot}991985}\right) = 66\frac{2}{3}\,(1 - 0{\cdot}98171) = 66\frac{2}{3}\,(0{\cdot}01829) = 1{\cdot}3717.$

Now, the average diameter of the iron pulley in the middle of its 4-in. face is 4·708 in. = 0·3923 ft., with a circumference of 1·2326 ft., and it is usual to run, at the least velocity, 1000 revolutions a minute; whence the power given by these pulleys = 1·3717 lb. × 4 in. × 1·2326 ft.

× 1000 revolutions = 6757 foot-pounds = $\frac{1}{8}$ HP. As the work performed by one of these centrifugal machines is the acquirement of velocity under the resistance of the friction of the machine and of the air, and the work of expelling the moisture is so insignificant in comparison that it may be neglected in estimating, it can be taken as probable that the real power demanded to keep the machine in motion is very nearly that given by calculation. It should be stated that the basket belonging to this particular machine is 29 in. diameter and 12 in. deep.

The second special case we instance at present consists in a proposed arrangement for driving a fan which had previously been found to demand an 8-in. belt on a 10-in. pulley to run it 1275 revolutions a minute. (The arc of contact here was 162°, so that the apparent power with a very tight belt was 37½ HP.: but about $\frac{1}{5}$ of this was defective adhesion from running a rigid belt over so small a pulley.) It was thought desirable to avoid the fast-running countershafts, and drive this direct from an engine-pulley fly-wheel, by impingement, so to speak, of the belt on its tight side between the fan-pulley and another larger carrier-pulley, against a portion of the periphery of the fly-wheel.

If we suppose the force demanded measured on the fan-pulley, as before, to be 40 HP. = 1,320,000, and the fan-pulley to be 10 in. diameter × 16 in. wide, and to run 1250 revolutions a minute; $\therefore \frac{1{,}320{,}000}{1250 \times 1\frac{3}{4} \times 16 \times \pi} = 25{\cdot}2$ as the pull, P, on each inch of width of the belt as it comes from the 10-in. pulley. By substituting this value for P in equation [5], and then reducing the equation to find the value for $a°$, we have $a° = 65°$, which is the angle of contact demanded to give the necessary adhesion.

It will be noticed that this angle is independent of the diameter of the fly-wheel pulley, it being only requisite that that diameter should be such as with the given or assumed number of revolutions will produce the given velocity. In the case taken for example, the fly-wheel pulley was 16 ft. diameter × 16 in wide, with 70 revolutions a minute velocity.

As we have before remarked, the sum of the two tensions on the belt is constant, whether the belt is performing work or not; that is, $S = T_2 + T_1$; but $P = T_2 - T_1$. $\therefore T_2 = T_1 - P$. $\therefore S = 2T_1 - P$.

As we assumed in equation [5] T to equal 66⅔ lbs., we can substitute the value of P as in Table I. in the equation, $S = 2(66\frac{2}{3}) - P = 133\frac{1}{3} - P$, from which it is evident that the sum of the tensions will vary with P or with the angle of contact. It is evident, also, that the load upon the shaft proceeding from the tensions $T_2$ and $T_1$ will be the resultant of whatever angle the belt makes with a line joining the centres of the two pulleys, or as the cosine of that angle.

By constructing on paper a pair of pulleys, it will be readily discerned that the angle in question for small pulleys = $90° - \frac{a}{2}$, and for large and crossed ones, = $\frac{a}{2} - 90°$, we can consequently form the following Table:—

TABLE III.—STRENGTH OF LACING OF JOINT 66⅔ LBS. THE INCH WIDE,

Showing, first, the sum of tensions on both sides of a belt to each inch of width, whether in motion or at rest, when strained to transmit the maximum quantity of power in general practice; and showing, second, the load carried by the shafts and supported constantly by the journals the inch of width of belt, when the arcs of contact vary as the angles of

| | 90° | 100° | 110° | 120° | 135° | 150° | 180° | 210° | 240° | 270° |
|---|---|---|---|---|---|---|---|---|---|---|
| | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. | lbs. |
| 1st, | 101· | 98·53 | 96·26 | 94·15 | 91·27 | 88·69 | 84·32 | 80·81 | 78· | 75·75 |
| 2nd, | 71·42 | 75·47 | 78·85 | 81·53 | 84·32 | 85·67 | 84·32 | 78·05 | 67·59 | 53·56 |

When machinery is driven by gearing, the shafts only carry the running wheels and the weight, and when the machines are thrown on, the friction of the lines increases with the work; but with belts and pulleys the load on the line and its frictional resistance is constant, whether the machinery works or lies idle.

It is not proper to assume that the load produced by the belt on the shaft is exactly that given by the second line in Table III.; but we can be safe in taking those weights as rarely exceeded, because belts begin to fail when they are; and as rarely much less, because few of our machines are not worked up to their belt of capacity.

The advantages shown by the figures on all the Tables, but especially on the last, in those arcs of contact over 180° where crossed belts are used, have the substantial ground of practice, although many mechanics are unaware of the facts. R. Briggs instances a case of several heavy grindstones having from main to counter lines 8-in. crossed belts on pulleys, 3 ft. diameter, running 120 revolutions, only 8 ft. centre to centre, where belts have already lasted, day and night use, three-and-a-half years. For the same purpose, 6-in. open belts were formerly used, with an average duration of a few weeks only.

Another use of a crossed belt is for long belts, the crossing effectually preventing those waves which generally impair, if they do not destroy, such belts when open.

We give a tabular record of the experiments of H. R. Towne, which will repay examination, as exhibiting several interesting and instructive facts connected with the efficiency of leather belts.

These experiments were made with leather belts of 3 and 6 in. width, and of the usual thickness—about $\frac{1}{16}$ths of an inch. The pulleys used were respectively of 12, 23¾, and 41 in. diameter, and were in each case fast upon their shafts. They were the ordinary cast-iron pulleys, turned on

the face, and, having already been in use for some years, were fair representatives of the pulleys usually found in practice.

Experiments were made first with a perfectly new belt, then with one partially used and in the best working condition, and finally with an old one, one which had been so long in use as to have deteriorated considerably, although not yet entirely worn out. The adhesion of the belts to the pulleys was not in any way influenced by the use of unguents or by wetting them: the new ones, when used, were just in the condition in which they were purchased; the others in the usual working condition of belts as found in machine-shops and factories—that is, they had been well greased, and were soft and pliable.

The manner in which the experiments were made was as follows:—The belt being suspended over the pulley, in the middle of its length, weights were attached to *one* side of the belt, and increased until the latter slipped freely over the pulley; the final, or *slipping*, weight was then recorded. Next, 5 lbs. were suspended on *each* side of the belt, and the additional weight required upon *one* side to produce slipping ascertained as before, and recorded. This operation was repeated with 10, 20, 30, 40, and 50 lbs., successively, suspended upon both sides of the belt. In the Tables, these weights, *plus* half the total weight of the belt, are given as the "equalizing weights" ($T_2$ in the formulas); and the *additional* weight required upon one side to produce slipping, is given under the head of "unbalanced weights;" this latter, *plus* the equalizing weight, gives the total tension on the loaded side of the belt ($T_1$ in the formulas).

The belt, in slipping over the pulley, moved at the rate of about 200 ft. a minute, and with a constant, rather than increasing, velocity; or, in other words, the final weight was such as to cause the belt to slip smoothly over the pulley, but not sufficient to entirely overcome the friction tending to keep the belt in a state of rest. In this case, that is, with an excessive weight, the velocity of the belt would have approximated to that of a falling body; while in the experiments its velocity was much slower, and was nearly constant, the friction acting precisely as a brake. By being careful that the final weight was such as to produce about the same velocity of the slipping belt in all of the experiments, reliable results were obtained.

It became necessary to make use of a weight such as would produce the positive motion of the belt described above, as it was found impossible to obtain any uniformity in the results when the attempt was made to ascertain the minimum weight which would cause the belt to slip. With much smaller weights *some* slipping took place, but it was almost inappreciable, and could only be noticed after the weight had hung for some minutes, and was due very probably to the imperceptible jarring of the building. After essaying for some time to conduct the experiments in this way, and obtaining only conflicting and unsatisfactory results, the attempt was abandoned, and the experiments made as first described.

In this way, as may be seen, results were obtained which compare together very favourably, and which contain only such discrepancies as will always be manifest in experiments of the kind. It is only by making a great number of trials and averaging their results, that reliable data can be obtained.

The value of the coefficient of friction which we deduce from our experiments is the mean of no less than 168 distinct trials.

It will be noticed, however, that the coefficient employed in the formulas is but *six-tenths* of the full value of that deduced from the experiments, the latter being 0·5853 and the former 0·4229. This reduction was made, after careful consideration, to compensate for the excess of weight employed in the experiments over that which would just produce slipping of the belt, and may be regarded as safe and reliable in practice.

A note is made, over the record of each trial, as to the condition of the weather at the time of making it—whether dry, damp, or wet; and it will be noticed that the adhesion of the belts to the pulleys was much affected by the amount of moisture in the atmosphere. It is to be regretted that this contingency was not provided for, and a careful record of the condition of the atmosphere kept by means of an *hygrometer*. The experiments indicate clearly, however, that the adhesion of the old and the partially-used belts was much increased in damp weather, and that they were then in their maximum state of efficiency. With the new belts, the indications are not so positive; but their efficiency seems to have been greatest when the atmosphere was in a dry condition.

Experiments were also made upon the tensile strength of belts, with the following results:—The weakest parts of an ordinary belt are the ends through which the lacing-holes are punched, and the belt is usually weaker here than the lacing itself. The next weakest points are the *splices* of the several pieces of leather which compose the belt, and which are here perforated by the holes for the copper rivets. The strengths of the new and the partially-used belts were found to be almost identical. The average of the trials is as follows:—

| | | | | |
|---|---|---|---|---|
| 3-in. belts broke through the | lace-holes | with | .. .. | 629 lbs. |
| " " | rivet | " " | .. .. | 1146 lbs. |
| " " | solid part | " | .. .. | 2025 lbs. |

These give as the strength to the *inch of width*:—

| | | | | |
|---|---|---|---|---|
| When the rupture is through the | lace-holes | .. | .. .. | 210 lbs. |
| " " | rivet | " .. | .. .. | 382 lbs. |
| " " | solid part | .. | .. .. | 675 lbs. |

The thickness being $\frac{7}{32}$ in. (= ·219), we have as the tensile strength of the leather 3086 lbs. a sq. in.

From the above we see that 200 lbs. an inch of width is the ultimate resistance to tearing that we can expect from ordinary belts.

The experiments herein described are strikingly corroborative of those already on record, and this gives increased assurance of their reliability; and, although there is nothing novel either in them or in their results, it is hoped that they will prove of interest, and that an examination of them will lead to confidence in the formulas which are based upon them.

### Three-Inch New Belt.

| On 12-inch Pulley (between Seams). | | | | | | On 12-inch Pulley (on Seams). | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ | Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
| | damp. | dry. | | | | | damp. | damp. | | | |
| 2·94 | 17 | 20 | 18·5 | 21·44 | 7·29 | 2·94 | 14 | 14 | 14·0 | 16·94 | 5·76 |
| 7·94 | 43 | 58 | 50·5 | 58·44 | 7·36 | 7·94 | 30 | 32 | 31·0 | 38·94 | 4·90 |
| 12·94 | 70 | 86 | 78·0 | 90·94 | 7·03 | 12·94 | 48 | 51 | 49·5 | 62·44 | 4·83 |
| 22·94 | 108 | 167 | 137·5 | 160·44 | 6·99 | 22·94 | 92 | 87 | 89·5 | 112·44 | 4·90 |
| 32·94 | 124 | 226 | 175·0 | 207·94 | 6·31 | 32·94 | 107 | 110 | 108·5 | 141·44 | 4·29 |
| 42·94 | 159 | 311 | 235·0 | 277·94 | 6·47 | 42·94 | 134 | 138 | 136·0 | 178·94 | 4·17 |
| 52·94 | 210 | 343 | 276·5 | 329·44 | 6·22 | 52·94 | 191 | 188 | 189·5 | 242·44 | 4·58 |
| | | | | Mean. | 6·810 | | | | | Mean. | 4·775 |

### Three-Inch New Belt.

| On 23½-inch Pulley. | | | | | | On 41-inch Pulley. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ | Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
| | damp. | damp. | | | | | dry. | dry. | | | |
| 2·94 | 12 | 16 | 14·0 | 16·94 | 5·76 | 2·94 | 13 | 13 | 13·0 | 15·94 | 5·42 |
| 7·94 | 34 | 44 | 39·0 | 46·94 | 5·91 | 7·94 | 38 | 39 | 38·5 | 46·44 | 5·85 |
| 12·94 | 54 | 77 | 65·5 | 78·44 | 6·06 | 12·94 | 55 | 61 | 58·0 | 70·94 | 5·48 |
| 22·94 | 110 | 135 | 122·5 | 145·44 | 6·34 | 22·94 | .. | .. | .. | .. | .. |
| 32·94 | 161 | 191 | 176·0 | 208·94 | 6·34 | 32·94 | 188 | 176 | 182·0 | 214·94 | 6·53 |
| 42·94 | 207 | 234 | 220·5 | 263·44 | 6·14 | 42·94 | .. | .. | .. | .. | .. |
| 52·94 | 277 | 282 | 279·5 | 332·44 | 6·28 | 52·94 | 289 | 295 | 292·0 | 344·94 | 6·52 |
| | | | | Mean. | 6·118 | | | | | Mean. | 5·960 |

### Three-Inch Belt.

Partially used and in good order—on 12-inch Pulley.

| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Trial No. 3. | Unbalanced Weight. Trial No. 4. | Unbalanced Weight. Trial No. 5. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
|---|---|---|---|---|---|---|---|---|
| | damp. | damp. | wet. | dry. | dry. | | | |
| 3·2 | 13 | 14 | 26 | 12 | 11 | 15·5 | 18·7 | 5·84 |
| 8·2 | 34 | 36 | 53 | 32 | 32 | 37·4 | 45·6 | 5·56 |
| 13·2 | 57 | 63 | 77 | 50 | 50 | 59·4 | 72·6 | 5·50 |
| 23·2 | 102 | 109 | 149 | 90 | 99 | 109·8 | 133·0 | 5·73 |
| 33·2 | 123 | 128 | 226 | 144 | 144 | 153·0 | 186·2 | 5·61 |
| 43·2 | 174 | 185 | 299 | 183 | .. | 210·2 | 253·4 | 5·87 |
| 53·2 | 226 | 265 | 338 | 249 | .. | 268·5 | 322·7 | 6·07 |
| | | | | | | | Mean .. | 5·754 |

THREE-INCH BELT—PARTIALLY USED AND IN GOOD ORDER.

| On 41-inch Pulley. | | | | | | On 23¾-inch Pulley. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ | Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Trial No. 3. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
| | dry. | dry. | | | | | damp. | damp. | dry. | | | |
| 3·2 | 26 | 25 | 25·5 | 28·7 | 8·97 | 3·2 | 23 | 22 | 23 | 22·6 | 25·8 | 8·06 |
| 8·2 | 59 | 55 | 57·0 | 65·2 | 7·95 | 8·2 | 53 | 54 | 53 | 53·3 | 61·5 | 7·50 |
| 13·2 | 86 | 82 | 84·0 | 97·2 | 7·36 | 13·2 | 86 | 89 | 82 | 85·6 | 98·8 | 7·48 |
| 23·2 | .. | .. | .. | .. | .. | 23·2 | .. | .. | 141 | .. | .. | .. |
| 33·2 | 188 | 194 | 190·5 | 223·7 | 6·74 | 33·2 | 194 | 210 | 181 | 195·0 | 228·2 | 6·87 |
| 43·2 | .. | .. | .. | .. | .. | 43·2 | .. | .. | 223 | .. | .. | .. |
| 53·2 | 306 | 323 | 314·5 | 367·7 | 6·91 | 53·2 | 285 | 316 | 272 | 291·0 | 344·2 | 6·47 |
| | | | | Mean . | 7·586 | | | | | | Mean . | 7·276 |

THREE-INCH OLD BELT.

| On 12-inch Pulley. | | | | | | On 23¾-inch Pulley. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ | Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
| | damp. | damp. | | | | | damp. | wet. | | | |
| 2·75 | 12 | 13 | 12·5 | 15·25 | 5·55 | 2·75 | 16 | 20 | 18·0 | 20·75 | 7·55 |
| 7·75 | 35 | 39 | 37·0 | 44·75 | 5·77 | 7·75 | 48 | 70 | 59·0 | 66·75 | 8·61 |
| 12·75 | 61 | 66 | 63·5 | 76·25 | 5·98 | 12·75 | 72 | 106 | 89·0 | 101·75 | 7·98 |
| 22·75 | 102 | 109 | 105·5 | 128·25 | 5·64 | 22·75 | 157 | 174 | 165·5 | 188·25 | 8·27 |
| 32·75 | 142 | 158 | 150·0 | 182·75 | 5·58 | 32·75 | 220 | 232 | 226·0 | 258·75 | 7·90 |
| 42·75 | 203 | 220 | 211·5 | 254·25 | 5·95 | 42·75 | 256 | 276 | 271·0 | 313·75 | 7·34 |
| 52·75 | 259 | 273 | 266·0 | 318·75 | 6·04 | 52·75 | 301 | 311 | 306·0 | 358·75 | 6·80 |
| | | | | Mean . | 5·787 | | | | | Mean . | 7·778 |

SIX-INCH NEW BELT.

| On 23⅝-inch Pulley. | | | | | | On 41-inch Pulley. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ | Equalizing Weights, or Initial Tension on each side of Belt $= T_2$. | Unbalanced Weight. Trial No. 1. | Unbalanced Weight. Trial No. 2. | Unbalanced Weight. Average of Trials. | Total Weight on loaded side of Belt when Belt slipped $= T_1$. | $\frac{T_1}{T_2}$ |
| | dry. | damp. | | | | | | | | | |
| 6·75 | 30 | 36 | 33·0 | 39·75 | 5·89 | 6·75 | 32 | 29 | 30·5 | 37·25 | 5·52 |
| 11·75 | 53 | 63 | 58·0 | 67·75 | 5·77 | 11·75 | 53 | 50 | 51·5 | 73·25 | 6·23 |
| 16·75 | 78 | 81 | 79·5 | 96·25 | 5·75 | 16·75 | 72 | 72 | 72·0 | 88·75 | 5·30 |
| 26·75 | 125 | 135 | 130·0 | 156·75 | 5·86 | 26·75 | 118 | 115 | 116·5 | 143·25 | 5·36 |
| 36·75 | 161 | 177 | 169·0 | 205·75 | 5·60 | 36·75 | 159 | 176 | 167·5 | 204·25 | 5·55 |
| 46·75 | 216 | 223 | 219·5 | 266·25 | 5·70 | 46·75 | 209 | 236 | 222·5 | 269·25 | 5·76 |
| 56·75 | 265 | 269 | 267·0 | 323·75 | 5·70 | 56·75 | 265 | 275 | 270·0 | 326·75 | 5·76 |
| | | | | Mean . | 5·752 | | | | | Mean . | 5·640 |

Belts and drums constitute the most convenient method of transmitting rotary motion from one shaft to another. Of late years their use has enormously increased, on account of their easy application in almost every case where power is required to be transferred. Compared with cog-wheel gearing, they possess several advantages, namely, the driving and driven shafts may be at a considerable distance from each other, and need not be parallel or in the same plane.

Belts and drums form very effective friction-couplings. If a machine driven by a belt becomes accidentally overloaded, the belt slips upon the drum, and a break-down is generally prevented.

By the introduction of fast and loose pulleys, the driven shaft can be set in motion or stopped with perfect safety, whilst the driving shaft is running at full speed. In cotton mills and other factories, where a number of independent machines are driven from a single shaft, this contrivance is of great value.

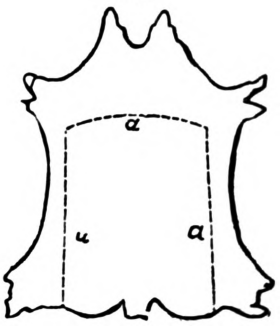
The motion of belts and drums is much smoother than that of gearing, and they can be readily applied to machines which require a high velocity, where ordinary gearing would be quite inadmissible.

*Material and Mode of Manufacture.*—Leather is generally used for the manufacture of belting. Other materials have been tried, such as india-rubber, gutta-percha, woven hemp, &c., but leather has been found to be the most reliable and economical in wear.

The best description of leather for the purpose is English ox-hide tanned with oak bark by the slow old-fashioned process, and dressed in such a way as to retain firmness and toughness, without harshness and rigidity.

The prime part of the hide only, called the *butt*, should be used, the other portions being comparatively loose, and only fit for inferior purposes.

646.

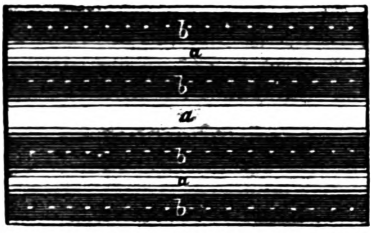



The dotted lines *a*, *a*, *a*, in Fig. 646 show the shape and size of the *butt*.

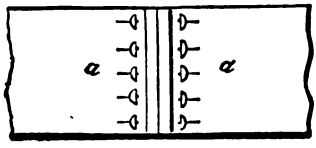
Butts are generally cut out of hides in the preliminary preparing process, and tanned by themselves. The time required for tanning best leather varies from twelve to eighteen months, according to the thickness. When the tanning is thoroughly completed, the butt is curried or dressed. During this process it must be stretched. This is effected by machinery, the leather being allowed to dry in its extended state. Strap-butts of best leather can be permanently extended from 4 to 5 in. For light work, belts of single substance are sufficient, the strips of leather being joined together by feather-edged splices, first cemented and then sewn. Single belting varies in thickness from $\frac{3}{16}$ to $\frac{1}{4}$ in. For heavy work, double and sometimes treble layers of leather are required, cemented and sewn through their entire length. The material used for the sewing is either strong well-waxed hemp, or thin strips of hide prepared with alum. The latter is generally used in the North of England; but its advantage over good waxed hemp is doubtful. The thickness of double belting is from $\frac{5}{16}$ to $\frac{7}{16}$ in.

An improvement in the ordinary double belt, shown in Figs. 647, 648, has been introduced by Messrs. Hepburn and Sons, of Southwark, who have given much attention to this branch of leather manufacture.

647.



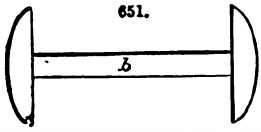

649.




650.

648.

651.




It consists in the substitution of a strip of prepared untanned hide for the outer layer of the belt, corrugated, as marked by *a a a* in Fig. 647: the inner one next the drum being made of tanned leather as usual, and not corrugated. This combination, or *composite belt* as it is called, has much greater strength than a belt composed of tanned leather only, and is not nearly so liable to stretch in working.

The sewing is also different. Instead of hand-labour being employed, these belts are sewn, or rather riveted, by machinery, and copper or malleable iron wire is used in place of waxed hemp, as shown in Figs. 647, 648.

Fig. 648 represents a longitudinal section of the belt through one of the lines of sewing, and shows the way in which each stitch or rivet is clenched and turned in.

This metallic sewing is also applied to double belting made entirely of leather, and has been found to work well, and to be more durable than ordinary hand-sewing.

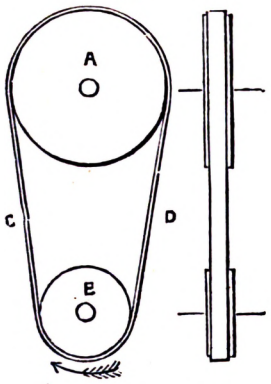
*Fastenings of Belts.*—Belts are usually laced together by thin strips of hide prepared with alum; from 12 to 18 in. is allowed for lap; and rows of holes at equal distances are punched in each end of the belt. A belt-fastener, which is extremely simple and effective, and requires no lap, is given full size in Fig. 651. It is made of tough metal, of various sizes to suit different thicknesses of belting; *a*, *a*, Figs. 649, 650, shows how this fastener is applied.

*Various Modes of Driving Drums.*—Fig. 652 represents the direct method, where the shafts of the drums are parallel and in the same plane. A is the driving drum, revolving in the

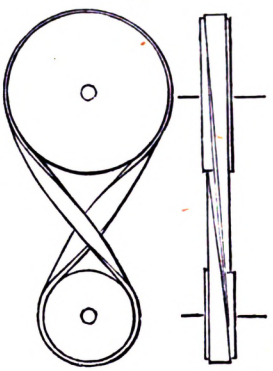
direction of the arrow; B is the driven drum. C is called the *leading* side of the belt; D the *following* side.

Belts are more effective when the leading side is underneath, as in Figs. 654, 655.

652.




653.



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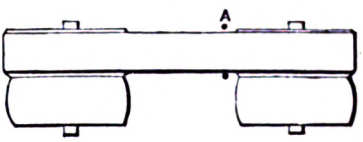
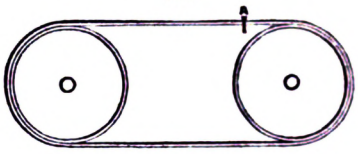
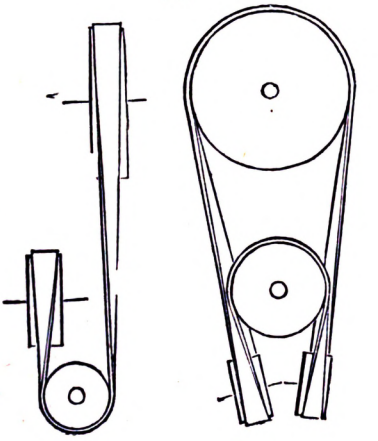



655.



656.



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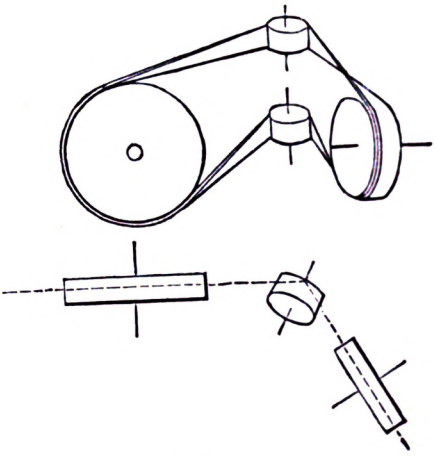
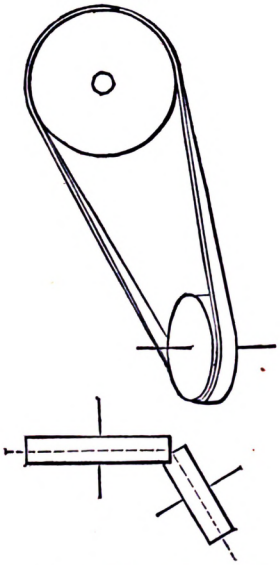
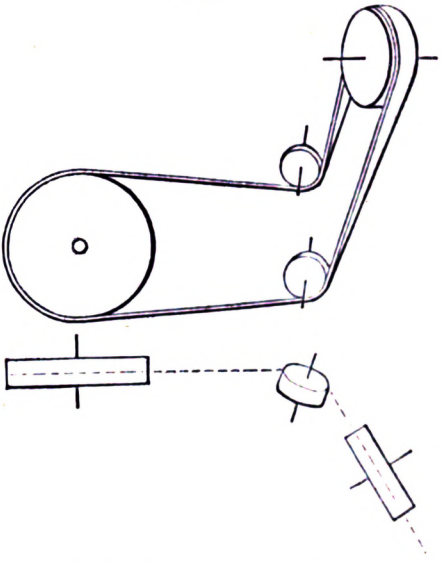


658.



659.



The drum should be rather wider than the belt, and slightly rounded on the face: $\frac{1}{16}$ths of an inch to the foot of width is sufficient convexity, except in the case of small high-speed pulleys, when it should be from $\frac{3}{8}$ to $\frac{1}{2}$ in.

Fig. 653 represents the crossed belt, which has the effect of making the drums revolve in opposite directions.

Figs. 654, 655, represent the fast and loose pulley.

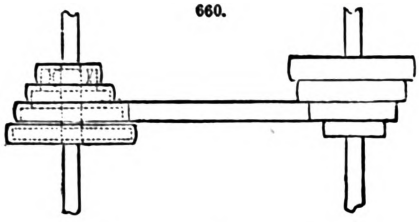
The fork for shifting the belt from the fast to the loose pulley must be placed at A, near the pulleys, and act on the following part of the belt.

Fig. 656 is a case where the shafts are parallel, but the drums not in the same plane; here it is necessary to lead the belt over guide-pulleys.

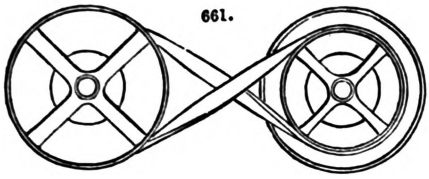
Fig. 657 is a similar case, where the shafts are in the same plane, but not parallel. In Fig. 658 the shafts are neither in the same plane, nor parallel; yet in this case no guide-pulleys are needed. Fig. 659 is a case where guide-pulleys are required.

Fig. 660 represents the most general way of varying the velocity-ratio of two shafts. The proportion of the respective diameters of each pair of pulleys is such that the sum of the two is always constant, and, therefore, the same length of belt will do for all the speeds.

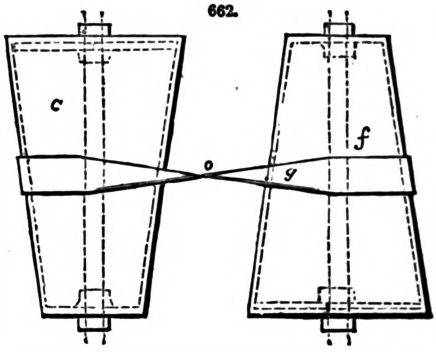
660.



661.



662.



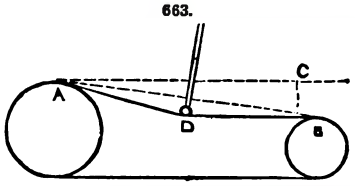

Figs. 661, 662, is a mode of varying the speed whilst the machinery is in motion. Two conical drums are placed in a reversed way to each other, so that the sum of any two corresponding diameters is always a constant quantity. The belt is made to move laterally along the surface of the cones, by certain contrivances; and thus a gradual increase or decrease of speed in the driven drum is brought about, on account of the constantly varying proportions of the two diameters, while the *angular velocity* of the driving drum remains constant.

*Tension-rollers.*—In order that the natural tension of the belts shall remain constant, and not exceed, though equalling, the value calculated, it is requisite to use *tension-rollers*.

The weight $q$ of these rollers is found by the approximate expression $q = \frac{2\,T_1 \cos.\, a}{\cos.\, b}$, wherein $a$ is half the obtuse angle A D B formed by the two branches of the belt upon which the weight rests, and may be assumed *a priori;* and $b$ the angle between the line A B and the horizontal line A C, Fig. 663. That is angle B A C = $b$.

This formula is reduced to the following rule :—

663.




To calculate the weight of a tension-roller, capable of producing its pressure upon the two branches of a belt, a given normal tension, as in Fig. 663.

Multiply the given normal tension by twice the cosine of half the obtuse angle formed by the two branches of the belt, and divide the product by the cosine of the angle formed by the common tangent of the two drums with the horizontal line A C.

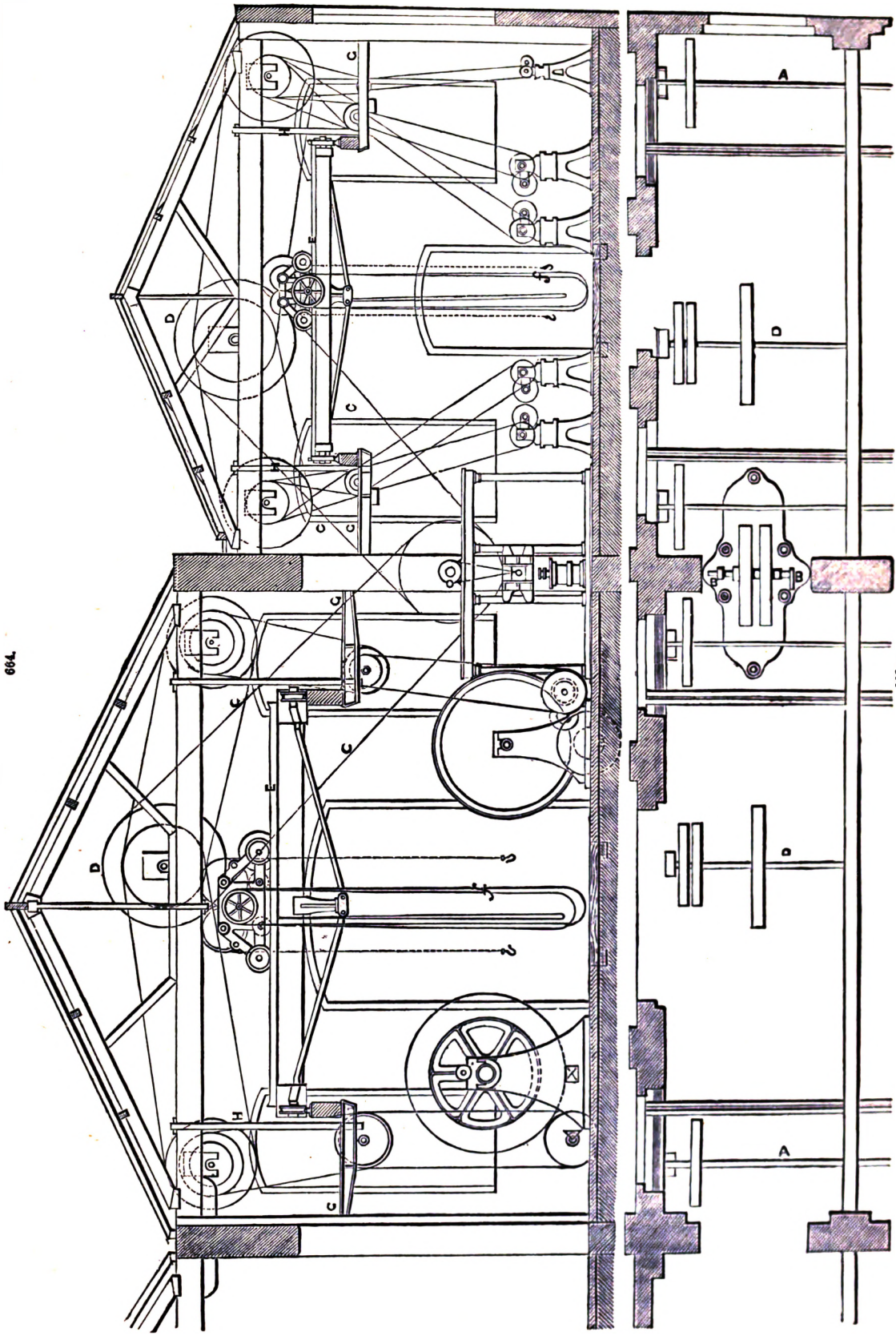
In fixing the belt, care must be taken to give it such a length that, when in repose, it shall only have a minimum flexure, and then the tension T will very nearly equal the value assigned to it by our previous developments.

Means must, of course, be reserved of increasing or diminishing at will the action of the roller.

If, owing to the particular arrangement of the drums, the tension-roller is not intended to act vertically, a suitable combination of levers may enable its action to be directed wheresoever it is necessary. The effort it exerts upon the belt perpendicularly to the line A B may then be calculated by the above rule, in supposing the angle $b$ to be nul and its cosine equal to one.

The general arrangement of the belting of Nasmyth, Wilson, and Co.'s mechanical workshops at Patricroft, near Manchester, shown in Figs. 664, 665, deserves particular attention.

The shop consists of two spans of 38 ft. and 48 ft. respectively, each having a length of 102 ft. It is lighted from the top by means of skylights, as indicated in Fig. 664. The smaller shop derives additional light from side-windows, close to which a row of small lathes is placed. The shafting A, A, is driven from a pair of vertical engines, fitted with balanced slide-valves, and having a pair of large pulleys fixed to their crank-shaft B, B, Fig. 665, in lieu of a fly-wheel. The straps from these pulleys are carried in opposite directions, so as to balance the strains produced by them; and one strap C, C, supplies power to the machinery of each span of the shop. The driving-shaft D, D, on the top of each span transmits power to two parallel lengths of shafting, one at each side of the two buildings; and for these also the belts balance their strains upon the


664.
665.
A
D
C
E
H
B

driving-shaft by being placed symmetrically in opposite directions. The machines are placed in parallel rows lengthways at both sides of the buildings, so as to have a clear wide space throughout the entire length of the shop for internal locomotion. By placing the smaller lathes in double rows in close proximity, and with their back-gearing against each other, it has been possible to put an unusual number of these tools into a limited space, still allowing free access to each machine, and giving a clear space in the centre for a passage. The workmen stand face to face, having the machines between them, and there is sufficient room for all their operations.

Each span is traversed by a travelling-crane E of suitable power. The cranes are capable of reaching every tool in the shop, and are worked by hand from below by means of endless cords *f*, *f*, passing round grooved pulleys attached to the gearing. The movements are in three directions; and, by provision of double-winding drums for the lifting-chains, it is possible to reach the extreme ends of the shop on either side. To facilitate the passage of the travellers and their chains, it was found necessary to avoid the use of vertical columns for supporting the longitudinal timbers which carry the crane-rails, and another mode of construction was substituted. The crane-rails are supported on horizontal cast-iron brackets G, G, secured at one end to the side columns or wall-standards, and having their free ends suspended from the cross-beams of the roof, as shown at H, H, Fig. 664. This mode of supporting the travellers is found to answer well, and it forms an element of great convenience with regard to the movement of heavy masses within the shop. The cast-iron brackets, at the same time, serve for the attachment of the hangers or bearings for the shafting, for which purpose wooden planks are fixed to them throughout the entire length of the shop in lines parallel to the side walls.

We append, with some slight alterations, an article on the driving-belt, by Edward Sang. This article, taken from the 'Practical Mechanic's Journal' (1866), will render clear the methods of investigation employed by Prony and Poncelet.

The first problem which presents itself when we consider the arrangement of the driving-belt, is to compute the length of the belt when the diameters of the wheels and the distance between their centres are known. If the machinery be in position, it is a very easy matter to measure the length of the required belt; and this direct measurement is even to be preferred to calculation, because ultimately the stretch of the belt has to be suited to the desired strain by trials. The converse problem, "Having given the length of the belt, to compute the diameters of the wheels," is much more important, because the process of repeated trial would be both tedious and expensive.

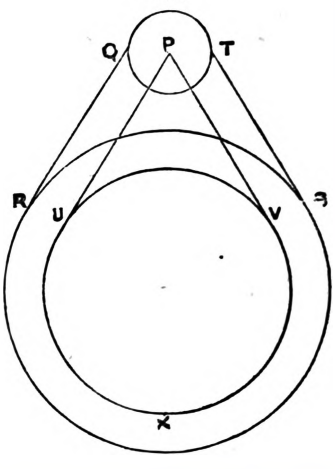
This converse problem arises when we have to design a set of speed-cones, which may, with one belt, give a variety of speeds. The solution of this converse problem is attended with considerable difficulty: it can only be accomplished, for practical purposes, by help of that modification of the method of trial and error which consists in tabulating a regular series of computed results.

In the 'Edinburgh Philosophical Journal' for April, 1831, E. Sang gave a table for this purpose, which had hardly been printed when an obvious improvement suggested itself. He reconstructed the table with this improvement, and thus describes the manner in which it is to be used.

In the first place, it is to be observed that there are *three* principal dimensions which have to be taken into consideration: these are the diameter of the wheel, the diameter of the pulley, and the distance between the centres. Now, it would be impossible to make a table of triple entry in which these three dimensions should enter as arguments, and the corresponding length of the belt as a result.

It is necessary, for the sake of abridgment, to assume one of these as constant; and that one which answers best is the distance between the centres. In the subjoined table this distance is announced to be *unit*.

666.




In the second place, if P represent the centre of the pulley, W that of the wheel, and Q R S T the belt passing over them, the inclination of the free parts, Q R and S T, to the line of centres depends only on the difference between the two diameters; so that if another pair were placed at the same centres, and having their diameters each 1 in., or any other quantity, more than those of the former pair, the inclination of the free parts of the band would be unchanged.

Thirdly, if we describe a circle round the centre, W, with a radius equal to the difference between the two radii, and draw from P the lines P U, P V to touch it, the entire line, P U X V P, is less than the length of the band, Q R S T, by the circumference of the pulley. Hence for each difference between the diameters, or for each inclination of the free part of the belt, there is a corresponding excess of the length of the belt above the circumference of the pulley, and also a corresponding excess of the same length of belt above the circumference of the wheel. By attention to these matters we can make our table one of single entry.

In the former table, Sang made the difference between the diameters the argument, and placed opposite to each difference the corresponding excess of the belt above the two circumferences. This arrangement made it necessary to multiply and to divide by 3·1415926. By the arrangement of the present table these multiplications and divisions are avoided.

If we compute the diameter of a wheel round which the belt would just go, and call the diameter of this wheel the *belt-diameter*; then, for each inclination, the excesses of the belt-diameter above the diameters of the wheel and pulley are determined. These excesses are entered in the table. Further-

more, Sang has made the inclination of the free part of the band the primary argument. In this way the arrangement of the table is as follows:—

Column 1 contains the inclinations of the free part of the belt to the line of centres, given for each half-degree of the centesimal system, that is, for each multiple of 27′ of the ordinary division; the values being given in ancient degrees and minutes, as well as in decimal parts of the right angle.

Column 2 contains the corresponding differences, W − P, between W, the diameter of the wheel, and P, the diameter of the pulley; the differences of these values are also given for the purpose of interpolation.

Column 3 contains the corresponding excesses, B − P, of the belt-diameter, B, above the diameter of the pulley, with the differences.

Column 4 contains the values of the excesses, B − W, of the same belt-diameter above the diameter of the wheel, also with their differences; the whole being given in decimal parts of the distance between the centres.

TABLE OF THE RELATIVE DIMENSIONS OF BELTS AND PULLEYS.

| Inclination. | | | W−P. | | B−P. | | B−W. | |
|---|---|---|---|---|---|---|---|---|
| ° | ′ | Decim. | Value. | Diff. | Value. | Diff. | Value. | Diff. |
| 0 | 00 | ·0000 | 0·00000 | 1571 | 0·63662 | 787 | ·63662 | 783 |
| 0 | 27 | ·0050 | 0·01571 | 1570 | 0·64449 | 792 | ·62879 | 780 |
| 0 | 54 | ·0100 | 0·03141 | 1571 | 0·65241 | 795 | ·62099 | 775 |
| 1 | 21 | ·0150 | 0·04712 | 1570 | 0·66036 | 798 | ·61324 | 772 |
| 1 | 48 | ·0200 | 0·06282 | 1570 | 0·66834 | 803 | ·60552 | 767 |
| 2 | 15 | ·0250 | 0·07852 | 1569 | 0·67637 | 806 | ·59785 | 763 |
| 2 | 42 | ·0300 | 0·09421 | 1569 | 0·68443 | 810 | ·59022 | 759 |
| 3 | 09 | ·0350 | 0·10990 | 1568 | 0·69253 | 814 | ·58263 | 755 |
| 3 | 36 | ·0400 | 0·12558 | 1567 | 0·70067 | 816 | ·57508 | 750 |
| 4 | 03 | ·0450 | 0·14125 | 1567 | 0·70883 | 821 | ·56758 | 746 |
| 4 | 30 | ·0500 | 0·15692 | 1565 | 0·71704 | 824 | ·56012 | 742 |
| 4 | 57 | ·0550 | 0·17257 | 1565 | 0·72528 | 827 | ·55270 | 737 |
| 5 | 24 | ·0600 | 0·18822 | 1563 | 0·73355 | 830 | ·54533 | 733 |
| 5 | 51 | ·0650 | 0·20385 | 1562 | 0·74185 | 834 | ·53800 | 728 |
| 6 | 18 | ·0700 | 0·21947 | 1560 | 0·75019 | 837 | ·53072 | 724 |
| 6 | 45 | ·0750 | 0·23507 | 1560 | 0·75856 | 840 | ·52348 | 719 |
| 7 | 12 | ·0800 | 0·25067 | 1557 | 0·76696 | 843 | ·51629 | 714 |
| 7 | 39 | ·0850 | 0·26624 | 1556 | 0·77539 | 846 | ·50915 | 710 |
| 8 | 06 | ·0900 | 0·28180 | 1554 | 0·79385 | 849 | ·50205 | 705 |
| 8 | 33 | ·0950 | 0·29734 | 1553 | 0·79234 | 852 | ·49500 | 701 |
| 9 | 00 | ·1000 | 0·31287 | 1550 | 0·80086 | 855 | ·48799 | 696 |
| 9 | 27 | ·1050 | 0.32837 | 1549 | 0 80941 | 857 | ·48103 | 691 |
| 9 | 54 | ·1100 | 0·34386 | 1546 | 0·81798 | 860 | ·47412 | 686 |
| 10 | 21 | ·1150 | 0·35932 | 1544 | 0·82658 | 863 | ·46726 | 681 |
| 10 | 48 | ·1200 | 0·37476 | 1542 | 0·83521 | 865 | ·46045 | 677 |
| 11 | 15 | ·1250 | 0·39018 | 1539 | 0·84386 | 868 | ·45368 | 671 |
| 11 | 42 | ·1300 | 0·40557 | 1537 | 0·85254 | 870 | ·44697 | 667 |
| 12 | 09 | ·1350 | 0·42094 | 1535 | 0·86124 | 873 | ·44030 | 662 |
| 12 | 36 | ·1400 | 0·43629 | 1531 | 0·86997 | 875 | ·43368 | 656 |
| 13 | 03 | ·1450 | 0·45160 | 1529 | 0·87872 | 877 | ·42712 | 652 |
| 13 | 30 | ·1500 | 0·46689 | 1526 | 0·88749 | 880 | ·42060 | 646 |
| 13 | 57 | ·1550 | 0·48215 | 1523 | 0·89629 | 881 | ·41414 | 642 |
| 14 | 24 | ·1600 | 0·49738 | 1520 | 0·90510 | 883 | ·40772 | 636 |
| 14 | 51 | ·1650 | 0·51258 | 1517 | 0·91393 | 886 | ·40136 | 632 |
| 15 | 18 | ·1700 | 0·52775 | 1513 | 0·92279 | 887 | ·39504 | 626 |
| 15 | 45 | ·1750 | 0·54288 | 1510 | 0·93166 | 889 | ·38878 | 621 |
| 16 | 12 | ·1800 | 0·55798 | 1507 | 0·94055 | 891 | ·38257 | 616 |
| 16 | 39 | ·1850 | 0·57305 | 1503 | 0·94946 | 892 | ·37641 | 611 |
| 17 | 06 | ·1900 | 0·58808 | 1500 | 0·95838 | 895 | ·37030 | 605 |
| 17 | 33 | ·1950 | 0·60308 | 1495 | 0·96733 | 895 | ·36425 | 600 |
| 18 | 00 | ·2000 | 0·61803 | 1492 | 0·97628 | 897 | ·35825 | 595 |
| 18 | 27 | ·2050 | 0·63295 | 1488 | 0·98525 | 899 | ·35230 | 590 |
| 18 | 54 | ·2100 | 0·64783 | 1485 | 0·99424 | 899 | ·34640 | 584 |
| 19 | 21 | ·2150 | 0·66268 | 1480 | 1·00323 | 901 | ·34056 | 579 |
| 19 | 48 | ·2200 | 0·67748 | 1475 | 1·01224 | 902 | ·33477 | 574 |

TABLE OF THE RELATIVE DIMENSIONS OF BELTS AND PULLEYS—*continued.*

| INCLINATION. | | | W–P. | | B–P. | | B–W. | |
|---|---|---|---|---|---|---|---|---|
| ° | ′ | Decim. | Value. | Diff. | Value. | Diff. | Value. | Diff. |
| 20 | 15 | ·2250 | 0·69223 | 1472 | 1·02126 | 904 | ·32903 | 568 |
| 20 | 42 | ·2300 | 0·70695 | 1467 | 1·03030 | 904 | ·32335 | 563 |
| 21 | 09 | ·2350 | 0·72162 | 1463 | 1·03934 | 905 | ·31772 | 558 |
| 21 | 36 | ·2400 | 0·73625 | 1458 | 1·04839 | 906 | ·31214 | 552 |
| 22 | 03 | ·2450 | 0·75083 | 1454 | 1·05745 | 906 | ·30662 | 547 |
| 22 | 30 | ·2500 | 0·76537 | 1449 | 1·06651 | 908 | ·30115 | 542 |
| 22 | 57 | ·2550 | 0·77986 | 1444 | 1·07559 | 908 | ·29573 | 536 |
| 23 | 24 | ·2600 | 0·79430 | 1439 | 1·08467 | 908 | ·29037 | 531 |
| 23 | 51 | ·2650 | 0·80869 | 1434 | 1·09375 | 909 | ·28506 | 525 |
| 24 | 18 | ·2700 | 0·82303 | 1429 | 1·10284 | 909 | ·27981 | 520 |
| 24 | 45 | ·2750 | 0·83732 | 1424 | 1·11193 | 910 | ·27461 | 514 |
| 25 | 12 | ·2800 | 0·85156 | 1419 | 1·12103 | 910 | ·26947 | 509 |
| 25 | 39 | ·2850 | 0·86575 | 1413 | 1·13013 | 909 | ·26438 | 503 |
| 26 | 06 | ·2900 | 0·87988 | 1408 | 1·13922 | 910 | ·25935 | 499 |
| 26 | 33 | ·2950 | 0·89396 | 1402 | 1·14832 | 910 | ·25436 | 492 |
| 27 | 00 | ·3000 | 0·90798 | 1397 | 1·15742 | 910 | ·24944 | 487 |
| 27 | 27 | ·3050 | 0·92195 | 1391 | 1·16652 | 909 | ·24457 | 482 |
| 27 | 54 | ·3100 | 0·93586 | 1385 | 1·17561 | 909 | ·23975 | 476 |
| 28 | 21 | ·3150 | 0·94971 | 1380 | 1·18470 | 909 | ·23499 | 471 |
| 28 | 48 | ·3200 | 0·96351 | 1373 | 1·19379 | 908 | ·23028 | 465 |
| 29 | 15 | ·3250 | 0·97724 | 1368 | 1·20287 | 908 | ·22563 | 460 |
| 29 | 42 | ·3300 | 0·99092 | 1361 | 1·21195 | 907 | ·22103 | 454 |
| 30 | 09 | ·3350 | 1·00453 | 1355 | 1·22102 | 906 | ·21649 | 449 |
| 30 | 36 | ·3400 | 1·01808 | 1349 | 1·23008 | 906 | ·21200 | 444 |
| 31 | 03 | ·3450 | 1·03157 | 1343 | 1·23914 | 904 | ·20756 | 438 |
| 31 | 30 | ·3500 | 1·04500 | 1336 | 1·24818 | 904 | ·20318 | 432 |
| 31 | 57 | ·3550 | 1·05836 | 1329 | 1·25722 | 902 | ·19886 | 427 |
| 32 | 24 | ·3600 | 1·07165 | 1323 | 1·26624 | 901 | ·19459 | 422 |
| 32 | 51 | ·3650 | 1·08488 | 1317 | 1·27525 | 900 | ·19037 | 416 |
| 33 | 18 | ·3700 | 1·09805 | 1309 | 1·28425 | 899 | ·18621 | 411 |
| 33 | 45 | ·3750 | 1·11114 | 1303 | 1·29324 | 897 | ·18210 | 406 |
| 34 | 12 | ·3800 | 1·12417 | 1295 | 1·30221 | 896 | ·17804 | 400 |
| 34 | 39 | ·3850 | 1·13712 | 1289 | 1·31117 | 894 | ·17404 | 394 |
| 35 | 06 | ·3900 | 1·15001 | 1282 | 1·32011 | 892 | ·17010 | 390 |
| 35 | 33 | ·3950 | 1·16283 | 1274 | 1·32903 | 891 | ·16620 | 384 |
| 36 | 00 | ·4000 | 1·17557 | 1267 | 1·33794 | 888 | ·16236 | 378 |
| 36 | 27 | ·4050 | 1·18824 | 1260 | 1·34682 | 887 | ·15858 | 373 |
| 36 | 54 | ·4100 | 1·20084 | 1252 | 1·35569 | 884 | ·15485 | 368 |
| 37 | 21 | ·4150 | 1·21336 | 1245 | 1·36453 | 883 | ·15117 | 363 |
| 37 | 48 | ·4200 | 1·22581 | 1238 | 1·37336 | 880 | ·14754 | 357 |
| 38 | 15 | ·4250 | 1·23819 | 1230 | 1·38216 | 877 | ·14397 | 352 |
| 38 | 42 | ·4300 | 1·25049 | 1222 | 1·39093 | 876 | ·14045 | 347 |
| 39 | 09 | ·4350 | 1·26271 | 1214 | 1·39969 | 872 | ·13698 | 341 |
| 39 | 36 | ·4400 | 1·27485 | 1206 | 1·40841 | 871 | ·13357 | 337 |
| 40 | 03 | ·4450 | 1·28691 | 1199 | 1·41712 | 867 | ·13020 | 331 |
| 40 | 30 | ·4500 | 1·29890 | 1190 | 1·42579 | 864 | ·12689 | 326 |
| 40 | 57 | ·4550 | 1·31080 | 1182 | 1·43443 | 862 | ·12363 | 320 |
| 41 | 24 | ·4600 | 1·32262 | 1175 | 1·44305 | 859 | ·12043 | 316 |
| 41 | 51 | ·4650 | 1·33437 | 1166 | 1·45164 | 855 | ·11727 | 310 |
| 42 | 18 | ·4700 | 1·34603 | 1157 | 1·46019 | 853 | ·11417 | 306 |
| 42 | 45 | ·4750 | 1·35760 | 1149 | 1·46872 | 849 | ·11111 | 300 |
| 43 | 12 | ·4800 | 1·36909 | 1141 | 1·47721 | 845 | ·10811 | 295 |
| 43 | 39 | ·4850 | 1·38050 | 1133 | 1·48566 | 842 | ·10516 | 290 |
| 44 | 06 | ·4900 | 1·39183 | 1123 | 1·49408 | 839 | ·10226 | 285 |
| 44 | 33 | ·4950 | 1·40306 | 1115 | 1·50247 | 835 | ·09941 | 281 |

TABLE OF THE RELATIVE DIMENSIONS OF BELTS AND PULLEYS—*continued.*

| INCLINATION. | | | W–P. | | B–P. | | B–W. | |
|---|---|---|---|---|---|---|---|---|
| ° | ′ | Decim. | Value. | Diff. | Value. | Diff. | Value. | Diff. |
| 45 | 00 | ·5000 | 1·41421 | 1107 | 1·51082 | 831 | ·09660 | 275 |
| 45 | 27 | ·5050 | 1·42528 | 1097 | 1·51913 | 827 | ·09385 | 270 |
| 45 | 54 | ·5100 | 1·43625 | 1089 | 1·52740 | 824 | ·09115 | 265 |
| 46 | 21 | ·5150 | 1·44714 | 1080 | 1·53564 | 819 | ·08850 | 261 |
| 46 | 48 | ·5200 | 1·45794 | 1070 | 1·54383 | 815 | ·08589 | 256 |
| 47 | 15 | ·5250 | 1·46864 | 1062 | 1·55198 | 811 | ·08333 | 250 |
| 47 | 42 | ·5300 | 1·47926 | 1053 | 1·56009 | 806 | ·08083 | 246 |
| 48 | 09 | ·5350 | 1·48979 | 1043 | 1·56815 | 803 | ·07837 | 242 |
| 48 | 36 | ·5400 | 1·50022 | 1034 | 1·57618 | 797 | ·07595 | 236 |
| 49 | 03 | ·5450 | 1·51056 | 1025 | 1·58415 | 793 | ·07359 | 232 |
| 49 | 30 | ·5500 | 1·52081 | 1016 | 1·59208 | 788 | ·07127 | 227 |
| 49 | 57 | ·5550 | 1·53097 | 1006 | 1·59996 | 784 | ·06900 | 223 |
| 50 | 24 | ·5600 | 1·54103 | 996 | 1·60780 | 778 | ·06677 | 218 |
| 50 | 51 | ·5650 | 1·55099 | 987 | 1·61558 | 774 | ·06459 | 213 |
| 51 | 18 | ·5700 | 1·56086 | 977 | 1·62332 | 768 | ·06246 | 209 |
| 51 | 45 | ·5750 | 1·57063 | 968 | 1·63100 | 763 | ·06037 | 205 |
| 52 | 12 | ·5800 | 1·58031 | 958 | 1·63863 | 758 | ·05832 | 200 |
| 52 | 39 | ·5850 | 1·58989 | 948 | 1·64621 | 753 | ·05632 | 195 |
| 53 | 06 | ·5900 | 1·59937 | 938 | 1·65374 | 747 | ·05437 | 191 |
| 53 | 33 | ·5950 | 1·60875 | 928 | 1·66121 | 741 | ·05246 | 187 |
| 54 | 00 | ·6000 | 1·61803 | 919 | 1·66862 | 736 | ·05059 | 183 |
| 54 | 27 | ·6050 | 1·62722 | 908 | 1·67598 | 730 | ·04876 | 178 |
| 54 | 54 | ·6100 | 1·63630 | 898 | 1·68328 | 724 | ·04698 | 174 |
| 55 | 21 | ·6150 | 1·64528 | 888 | 1·69052 | 718 | ·04524 | 170 |
| 55 | 48 | ·6200 | 1·65416 | 878 | 1·69770 | 713 | ·04354 | 165 |
| 56 | 15 | ·6250 | 1·66294 | 867 | 1·70483 | 705 | ·04189 | 162 |
| 56 | 42 | ·6300 | 1·67161 | 858 | 1·71188 | 700 | ·04027 | 158 |
| 57 | 09 | ·6350 | 1·68019 | 847 | 1·71888 | 694 | ·03869 | 153 |
| 57 | 36 | ·6400 | 1·68866 | 836 | 1·72582 | 687 | ·03716 | 150 |
| 58 | 03 | ·6450 | 1·69702 | 826 | 1·73269 | 680 | ·03566 | 145 |
| 58 | 30 | ·6500 | 1·70528 | 815 | 1·73949 | 674 | ·03421 | 142 |
| 58 | 57 | ·6550 | 1·71343 | 805 | 1·74623 | 667 | ·03279 | 138 |
| 59 | 24 | ·6600 | 1·72148 | 795 | 1·75290 | 660 | ·03141 | 134 |
| 59 | 51 | ·6650 | 1·72943 | 783 | 1·75950 | 653 | ·03007 | 130 |
| 60 | 18 | ·6700 | 1·73726 | 773 | 1·76603 | 647 | ·02877 | 127 |
| 60 | 45 | ·6750 | 1·74499 | 762 | 1·77250 | 639 | ·02750 | 122 |
| 61 | 12 | ·6800 | 1·75261 | 752 | 1·77889 | 632 | ·02628 | 120 |
| 61 | 39 | ·6850 | 1·76013 | 740 | 1·78521 | 625 | ·02508 | 115 |
| 62 | 06 | ·6900 | 1·76753 | 730 | 1·79146 | 617 | ·02393 | 113 |
| 62 | 33 | ·6950 | 1·77483 | 718 | 1·79763 | 610 | ·02280 | 108 |
| 63 | 00 | ·7000 | 1·78201 | 708 | 1·80373 | 602 | ·02172 | 106 |
| 63 | 27 | ·7050 | 1·78909 | 697 | 1·80975 | 595 | ·02066 | 101 |
| 63 | 54 | ·7100 | 1·79606 | 685 | 1·81570 | 587 | ·01965 | 99 |
| 64 | 21 | ·7150 | 1·80291 | 674 | 1·82157 | 579 | ·01866 | 95 |
| 64 | 48 | ·7200 | 1·80965 | 664 | 1·82736 | 571 | ·01771 | 92 |
| 65 | 15 | ·7250 | 1·81629 | 652 | 1·83307 | 564 | ·01679 | 89 |
| 65 | 42 | ·7300 | 1·82281 | 640 | 1·83871 | 555 | ·01590 | 86 |
| 66 | 09 | ·7350 | 1·82921 | 630 | 1·84426 | 547 | ·01504 | 82 |
| 66 | 36 | ·7400 | 1·83551 | 618 | 1·84973 | 538 | ·01422 | 80 |
| 67 | 03 | ·7450 | 1·84169 | 607 | 1·85511 | 530 | ·01342 | 77 |
| 67 | 30 | ·7500 | 1·84776 | 595 | 1·86041 | 522 | ·01265 | 73 |
| 67 | 57 | ·7550 | 1·85371 | 584 | 1·86563 | 513 | ·01192 | 71 |
| 68 | 24 | ·7600 | 1·85955 | 573 | 1·87076 | 505 | ·01121 | 68 |
| 68 | 51 | ·7650 | 1·86528 | 561 | 1·87581 | 496 | ·01053 | 65 |
| 69 | 18 | ·7700 | 1·87089 | 549 | 1·88077 | 486 | ·00988 | 63 |

TABLE OF THE RELATIVE DIMENSIONS OF BELTS AND PULLEYS—*continued.*

| INCLINATION. | | | W–P. | | B–P. | | B–W. | |
|---|---|---|---|---|---|---|---|---|
| ° | ′ | Decim. | Value. | Diff. | Value. | Diff. | Value. | Diff. |
| 69 | 45 | ·7750 | 1·87638 | 538 | 1·88563 | 478 | ·00925 | 60 |
| 70 | 12 | ·7800 | 1·88176 | 526 | 1·89041 | 470 | ·00865 | 57 |
| 70 | 39 | ·7850 | 1·88702 | 515 | 1·89511 | 459 | ·00808 | 55 |
| 71 | 06 | ·7900 | 1·89217 | 503 | 1·89970 | 451 | ·00753 | 52 |
| 71 | 33 | ·7950 | 1·89720 | 491 | 1·90421 | 442 | ·00701 | 49 |
| 72 | 00 | ·8000 | 1·90211 | 480 | 1·90863 | 432 | ·00652 | 48 |
| 72 | 27 | ·8050 | 1·90691 | 468 | 1·91295 | 423 | ·00604 | 45 |
| 72 | 54 | ·8100 | 1·91159 | 456 | 1·91718 | 413 | ·00559 | 43 |
| 73 | 21 | ·8150 | 1·91615 | 444 | 1·92131 | 404 | ·00516 | 40 |
| 73 | 48 | ·8200 | 1·92059 | 432 | 1·92535 | 394 | ·00476 | 39 |
| 74 | 15 | ·8250 | 1·92491 | 420 | 1·92929 | 384 | ·00437 | 36 |
| 74 | 42 | ·8300 | 1·92911 | 409 | 1·93313 | 374 | ·00401 | 34 |
| 75 | 09 | ·8350 | 1·93320 | 397 | 1·93687 | 364 | ·00367 | 32 |
| 75 | 36 | ·8400 | 1·93717 | 384 | 1·94051 | 355 | ·00335 | 31 |
| 76 | 03 | ·8450 | 1·94101 | 373 | 1·94406 | 344 | ·00304 | 28 |
| 76 | 30 | ·8500 | 1·94474 | 361 | 1·94750 | 334 | ·00276 | 27 |
| 76 | 57 | ·8550 | 1·94835 | 348 | 1·95084 | 324 | ·00249 | 24 |
| 77 | 24 | ·8600 | 1·95183 | 337 | 1·95408 | 313 | ·00225 | 24 |
| 77 | 51 | ·8650 | 1·95520 | 325 | 1·95721 | 303 | ·00201 | 21 |
| 78 | 18 | ·8700 | 1·95845 | 312 | 1·96024 | 293 | ·00180 | 20 |
| 78 | 45 | ·8750 | 1·96157 | 300 | 1·96317 | 282 | ·00160 | 18 |
| 79 | 12 | ·8800 | 1·96457 | 289 | 1·96599 | 271 | ·00142 | 17 |
| 79 | 39 | ·8850 | 1·96746 | 276 | 1·96870 | 261 | ·00125 | 16 |
| 80 | 06 | ·8900 | 1·97022 | 264 | 1·97131 | 250 | ·00109 | 14 |
| 80 | 33 | ·8950 | 0·97286 | 252 | 1·97381 | 239 | ·00095 | 13 |
| 81 | 00 | ·9000 | 1·97538 | 239 | 1·97620 | 228 | ·00082 | 12 |
| 81 | 27 | ·9050 | 1·97777 | 228 | 1·97848 | 217 | ·00070 | 10 |
| 81 | 54 | ·9100 | 1·98005 | 215 | 1·98065 | 205 | ·00060 | 10 |
| 82 | 21 | ·9150 | 1·98220 | 203 | 1·98270 | 195 | ·00050 | 8 |
| 82 | 48 | ·9200 | 1·98423 | 191 | 1·98465 | 183 | ·00042 | 7 |
| 83 | 15 | ·9250 | 1·98614 | 178 | 1·98648 | 172 | ·00035 | 7 |
| 83 | 42 | ·9300 | 1·98792 | 166 | 1·98820 | 161 | ·00028 | 5 |
| 84 | 09 | ·9350 | 1·98958 | 154 | 1·98981 | 149 | ·00023 | 5 |
| 84 | 36 | ·9400 | 1·99112 | 142 | 1·99130 | 138 | ·00018 | 4 |
| 85 | 03 | ·9450 | 1·99254 | 129 | 1·99268 | 126 | ·00014 | 4 |
| 85 | 30 | ·9500 | 1·99383 | 118 | 1·99394 | 114 | ·00010 | 3 |
| 85 | 57 | ·9550 | 1·99501 | 104 | 1·99508 | 103 | ·00007 | 2 |
| 86 | 24 | ·9600 | 1·99605 | 93 | 1·99611 | 90 | ·00005 | 1 |
| 86 | 51 | ·9650 | 1·99698 | 80 | 1·99701 | 79 | ·00004 | 2 |
| 87 | 18 | ·9700 | 1·99778 | 68 | 1·99780 | 67 | ·00002 | 1 |
| 87 | 45 | ·9750 | 1·99846 | 55 | 1·99847 | 55 | ·00001 | 0 |
| 88 | 12 | ·9800 | 1·99901 | 43 | 1·99902 | 43 | ·00001 | 1 |
| 88 | 39 | ·9850 | 1·99944 | 31 | 1·99945 | 30 | ·00000 | 0 |
| 89 | 06 | ·9900 | 1·99975 | 19 | 1·99975 | 19 | ·00000 | 0 |
| 89 | 33 | ·9950 | 1·99994 | 6 | 1·99994 | 6 | ·00000 | 0 |
| 90 | 00 | 1·0000 | 2·00000 | .. | 2·00000 | .. | ·00000 | .. |

In order to make the use of this table clear, we give an example:—

Let the distance between the centres be 26 in., the first diameter on the wheel 27 in., the first on the pulley 3·65, and the fourth on the pulley 7·80, it is required to compute the fourth diameter on the wheel.

The first business is to reduce these dimensions to decimal parts of the distance between the centres; this is done by dividing them all by 26; the results are $W_1 = 1·03846$; $P_1 = ·14038$; $P_4 = ·30000$. From these we find $W_1 - P_1 = ·89808$, and we have to seek, by help of the table, the corresponding value of $B - P_1$. Now, the nearest number to the above ·89808 which we find in the table is ·89396, which corresponds to $B - P = 1·14832$; we have, therefore, to make a correction by interpolating by means of the proportion 1402 : 910 :: 412 : 267; wherefore the value of $B - P_1$ comes out 1·15099, and adding to this the value of $P_1$ we have the belt-diameter $B = 1·29137$. (If it were worth while, we might convert this into inches, obtaining 33·5756 in.

for the diameter of the wheel round which the belt would just fit, and giving 105·48 in. for the length of the belt itself.)

Subtracting the fourth pulley diameter, namely, ·30000, from this, we find $B - P_4 = ·99137$. Seeking in the proper column for this number, we find ·98525, differing from what is wanted by 612. The corresponding tabular value of $W - P$ is ·63295, which has to be corrected by interpolation, thus, 899 : 1488 :: 612 : 1013, giving the true value $W_4 - P_4 = ·64308$: wherefore $W_4 = ·94308$, or in inches 24·52, which is the dimension sought for. The calculation may be arranged thus:—

| | | |
|---|---|---|
| $W_1$ | = | 1·03846 |
| $P_1$ | = | ·14038 |
| $W_1 - P_1$ | = | ·89808 |
| Table | | ·89396 |
| Tabular Error | | 412; 1402 : 910 :: 412 : 267 |
| Table | | 1·14832 |
| Correction | + | 267 |
| $B - P_1$ | = | 1·15099 |
| $P_1$ | = | ·14038 |
| B | = | 1·29137 |
| $P_4$ | = | ·30000 |
| $B - P_4$ | = | ·99137 |
| Table | | ·98525 |
| Error | | 612; 899 : — 1488 :: 612 : 1013 |
| Table | | ·63295 |
| Correction | + | 1013 |
| $W_4 - P_4$ | = | ·64308 |
| $P_4$ | = | ·30000 |
| $W_4$ | = | ·94308 = 24·520 in. |

To this it may be necessary to add an example in which the diameter of the pulley is wanted:—

Let the distance between the centres be 27·5 in., the lesser diameter on the pulley 3·5, the greater diameter on the wheel 27, and the lesser diameter on the wheel 24; and let us compute the corresponding greater diameter on the pulley.

Dividing all by 27·5, we obtain $P_1 = ·12727$, $W_1 = ·98182$, $W_2 = ·87273$; whence

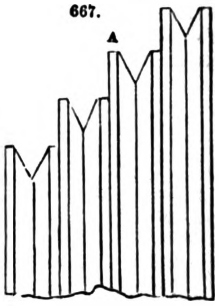
| | | |
|---|---|---|
| $W_1$ | = | ·98182 |
| $P_1$ | = | ·12727 |
| $W_1 - P_1$ | = | ·85455 |
| Table | | ·85156 |
| Error | | 299; 1419 : — 509 :: 299 : — 107 |
| Table | | ·26947 |
| Correction | − | 107 |
| $B - W_1$ | = | ·26840 |
| $W_1$ | = | ·98182 |
| B | = | 1·25022 |
| $W_2$ | = | ·87273 |
| $B - W_2$ | = | ·37749 |
| Table | | ·38257 |
| Error | − | 508; — 616 : 1507 :: — 508 : 1243 |
| Table | | ·55798 |
| Correction | + | 1243 |
| $W_2 - P_2$ | = | ·57041 |
| $W_2$ | = | ·87273 |
| $P_2$ | = | ·30232 = 8·314 in. |

If a set of pulleys and wheels be suited to each other, so that one band may go round each pair, and if another set be made by augmenting all the diameters by one and the same quantity, then

this second set also will have the property of being suited to one band. Hence, if a pair of driving cones be suited to a belt of one thickness, they will also suit a belt of any other thickness.

When we have to do with wheels to be driven by means of round bands, and in which the edges are grooved, it is convenient to make the calculations as for the diameters of the cylindric surfaces A A, into which the grooves are to be cut, and we must take care, after these cylindric fillets are dressed, to cut all the grooves to one gauge. This being done, and a band of any thickness being fitted to one pair of grooves, the same band will fit the remaining pairs.

667.




When the belts are to be crossed, there is no trouble in computing the diameters; for if the sum of the two diameters be kept the same, the length of the belt remains unchanged. In order to compute the length of a crossed belt, we have only to enter the column titled W — P with the sum of the diameters instead of their difference, and then the corresponding value in the column B — P is the belt diameter. Such a computation is very seldom needed, but merely for the sake of completeness an example is added.

The distance between the centres being 30 in., and the diameters of the wheel and pulley being 43 in. and 7 in. respectively, the length of the crossed belt is wanted.

Here the sum of the diameters is 50 in.: this divided by 30 gives W + P = 1·66667: hence

| | | |
|---|---|---|
| W + P .. .. .. .. .. .. | 1·66667 | |
| Table .. .. .. .. .. .. | 1·66294 | |
| Error .. .. .. .. .. .. | 373 | 867 : 705 :: 373 : 303 |
| Table .. .. .. .. .. .. | 1·70483 | |
| Correction .. .. .. .. + | 303 | |
| B .. .. .. .. .. .. = | 1·70786 = 51·236 in. | |

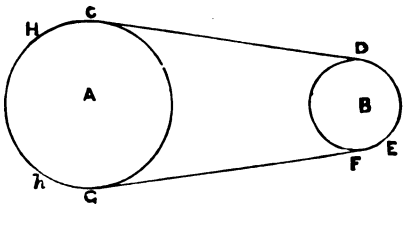
whence the length of the crossed belt is 161·05 in.

When a belt is passed over the circumferences of two pulleys, so as to connect the motion of the one with that of the other, it seems as if the velocities of these two circumferences ought to be alike; and that difference which is observed whenever a belt is used for communicating determinate velocities, has been attributed to the slipping of the belt, or to that imaginary cause, *the imperfection of machinery*. The actions of machines, however, are governed by laws as exact and invariable as those which regulate the motions of the planets; and what we call the imperfections of those actions are only evidences of our ignorance of, or our inattention to, those properties of matter from which they inevitably follow. These accommodations, as we may call them, are essential to the comfortable action of machines, and bring within our reach the use of contrivances which would otherwise demand unattainable perfection in workmanship. An investigation of the action of the driving-belt shows that its supposed imperfection is an accompaniment essential to this mode of propulsion, and governed, like all other natural phenomena, by precise laws.

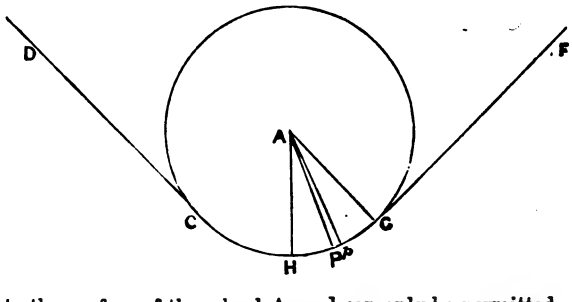
To place the nature of the action in a clear light, let Fig. 668 represent a pair of wheels connected by a belt, A being the centre of the driving, B that of the driven wheel, and C D E F G H the belt moving in the direction of the letters.

The apparatus being brought to rest, and the tensions on the two open parts, C D and F G, of the belt being alike, let us attempt to put it in motion by applying pressure to the wheel A. The wheel B will not begin to move until A has first turned a little round, so as, by augmenting the tension on F G, and relaxing that on C D, to create a difference of tension sufficient to overcome the resistance offered to the motion of the wheel B. But this difference of tension can only be

668.




669




created by the adhesion of the belt G C H to the surface of the wheel A, and can only be permitted to exist by the similar adhesion of D E F to the surface of the wheel B. And again, these frictions necessarily depend on the pressure which the belts exert upon the surface of each wheel; so that the first branch of our inquiry must be into the law of the pressure of a belt against the curved surface to which it is applied.

Let then F G H C D, Fig. 669, represent a belt which, while kept to a uniform tension, has been partially wound on the circumference of the wheel A. Our business is to discover the pressure which the belt exerts against each portion of the arc G C H.

Having bisected the arc of contact in H, assume a small element P $p$ of the half H G; the pressure on this minute portion of the circumference of the wheel, necessarily directed to the centre A, may be decomposed into two portions, one parallel to and the other perpendicular to H A. That part which is perpendicular to H A is balanced by a similar pressure obtained from the corresponding element of the arc H C, and so is eliminated; but that part which is parallel to H A is augmented by the analogous pressure on the other side, and the sum or integral of all such pressures must make up the resultant of the tensions of the two free parts of the belt. If we put $r$ for the radius of the wheel, $a$ for the angle H A P, and $da$ for the minute increment P A $p$ ($da$ is termed the differential of a very small angle, not $d \times a$; this is the very clumsy notation of the differential calculus), also $p$ for the pressure of the belt against a linear unit of the circumference, $p\,r\,da$ must represent the pressure of the belt against the arc P $p$, of which the length is $r\,da$.

This pressure, $p\,r\,da$, acting in the direction P A, gives, when estimated in the direction H A, the value $p\,r$, cos. $a$, $da$. The integral of this for the angle $a$ is $p\,r$ sin. $a$, and therefore if A represent the angle H A G, $2\,p\,r$ sin. A is the value of the whole pressure of the belt against the surface G H C, estimated in the direction H A. But if $s$ be put for the uniform strain on the belt, $2\,s$ sin. A is the value of the resultant of the two tensions G F and C D, wherefore $p\,r = s$, because $2\,p\,r$ sin. A $= 2\,s$ sin. A; that is to say—

*The pressure of the belt against a portion of the circumference equal in length to the radius is just equal to the strain on the belt.*

Or, as it may otherwise be stated, *The pressure against a linear unit of the circumference is equal to the tension of the belt divided by the number of the linear units in the radius of curvature, since* $p = \frac{s}{r}$.

Before proceeding to apply this principle to the investigation of friction, it is necessary to point out one or two important corollaries:—

When a cord, supposed to be of uniform tension, is wound round any object which is not cylindric, the pressure is greatest upon those parts which are most salient, since the radius of curvature there is the least, and therefore the tendency is to bring the object nearer to the cylindric form.

Again, if a belt be passed over two wheels of different diameters, the pressure per linear inch is greater on the circumference of the smaller wheel, and hence the tear and wear both of the belt and of the surface must be greater there: and since the parts of the smaller wheel come more frequently round to be acted on than do those of the larger, it follows that the abrasion on the lesser wheel is greater than that on the larger, roughly, in the inverse ratio of the squares of their diameters. This is in accordance with the fact, well known to turners, that the pulley-groove wears away many times faster than the groove in the fly-wheel.

When a guide-pulley is used to deflect or to tighten a band, the pressure upon it is inversely proportional to the radius of the pulley; and the injury done to it must, on account of the greater flexure, be in a still higher ratio: hence the importance of having such pulleys made as large as circumstances will allow. It is to be remarked that the angle of deflection has nothing to do with this action, which remains the same however small or however great the arc of contact may be; the amount of deflection, however, has to do with the friction on the axis of the pulley, and cannot be overlooked in an estimate of the general working of the machinery.

When the radius of curvature is very small, the injury done to the surface of the belt by what may be called a mere contact, becomes very great, being inversely as the radius of curvature and directly as the tension: hence the ease with which a tight cord is cut. The edge of the knife has its radius of curvature excessively small, and its penetrating power is enormous.

In this investigation we have assumed the belt to be uniformly tense, and the surface to be uniformly curved throughout. To accommodate the result to those cases in which the tension and the curvature are variable, we must restrict the formula to an infinitesimal portion of the arc of contact. Thus, if $a$ be the inclination of the normal to a fixed line, $r$ the radius of curvature of the arc, and therefore $r\,da$ the length of an element of that arc, we shall have $p\,r\,da = s\,da$, so that the pressure of the belt against a small portion of the curved surface is proportional to its angular extent and to the tension of the belt, without reference to the radius of curvature. Supposing the tension to be alike, the pressure of the belt on one degree of the circumference of the pulley is just equal to its pressure on one degree of the circumference of the wheel.

When the tension of the belt is not uniform, there must be a tendency to slip from those parts where the tension is small towards those where the tension is great, and this tendency can only be counteracted by the friction on the intermediate surface. So long as this friction exceeds the difference between the two tensions there can be no change; but whenever the difference of tension exceeds the friction on the intermediate arc of contact the belt must slip. Thus, if the belt at G, Fig. 670, be strained to a tension S, while at P the tension is only $s$, there can be no slipping when the friction on the intermediate arc G P is greater than S $- s$; and therefore, if the belt be actually slipping, or on the point of slipping, the friction on G P must be exactly equal to the difference between the strains S and $s$.

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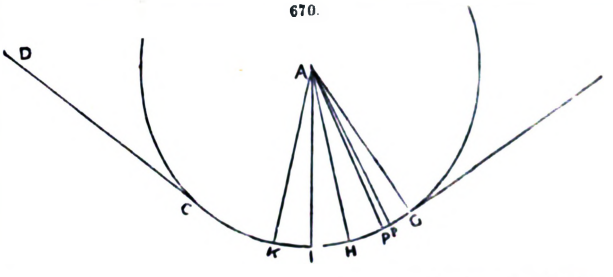


Experiment has shown that, for all practical purposes, friction may be regarded as bearing to the pressure a ratio constant for the same materials, but varying from one material to another;

and this ratio, represented by what is called the coefficient of friction, has been determined for a great variety of substances. Let us put $f$ for this coefficient, so that, $p$ being the pressure, $fp$ may be the corresponding friction.

Take now P$p$, a minute increment to the arc CP; the difference between the tensions at P and $p$, when the belt is slipping, must be equal to the friction on the intermediate arc P$p$. Now, although in strictness the tension augments from P to $p$, yet when P$p$ is supposed to be infinitesimally minute, we may neglect this variation, and assume that the pressure upon the arc P$p$ is $s\,da$, and that, therefore, the friction upon that arc is $f\,s\,da$. In this way the increment of the tension from P to $p$ becomes $ds = f\,s\,da$, whence $\frac{ds}{s} = f\,da$.

It is well known that the quotient of the differential of a variable by the variable itself, is the differential of the hyperbolic logarithm of that variable; wherefore, passing from differentials to their integrals, we have $fa = \log._\epsilon s +$ constant.

If then A and $a$ be the inclinations of two normals to a fixed line, S and $s$ the tensions of the belt at their extremities, we must have $f\,\mathrm{A} = \log._\epsilon \mathrm{S} +$ constant, $f\,a = \log._\epsilon s +$ constant, and subtracting, in order to eliminate the intermediate constant introduced by the integration, we get

$$f\,(\mathrm{A} - a) = \log._\epsilon \frac{\mathrm{S}}{s}.$$

It thus appears that, when a belt is slipping, the difference between the logarithms of the tensions at two points is proportional to the angular interval between those points, without any regard to the radius of curvature, and that, therefore, this law holds good of unequably as well as of uniformly curved surfaces.

If we measure off a series of equal angles, G A P, P A H, H A I, I A K, and so on, the logarithms of the tensions at the points G, P, H, I, K, and so on, must be in arithmetical progression, and the tensions themselves in continued proportion: this is also evident when we put the above equation under the form $\frac{\mathrm{S}}{s} = \epsilon^{f(\mathrm{A}-a)}$, in which $\epsilon$ is the basis of the hyperbolic system of logarithms.

In order to prepare the above formula for actual use, we convert the neperian into common logarithms by multiplying each side of the equation by $\mathrm{M} = \cdot 43429\ 44819$, and so on, the modulus of common logarithms, and obtain $\mathrm{M}f\,(\mathrm{A} - a) = \log. \frac{\mathrm{S}}{s}$.

But here again the angles A and $a$ are represented by arcs measured in parts of the radius, whereas it is customary to estimate them in degrees. Now, for half a turn $\mathrm{A} - a$ is $\pi = 3 \cdot 14159\ 26536$, wherefore for 1° of the ancient (or common) division the difference of logarithms must be $\mathrm{M}f\frac{\pi}{180}$, or for one degree of the modern division $\mathrm{M}f\frac{\pi}{200}$. Wherefore if $a°$ be the number of ancient, $a^c$ the number of centesimal degrees over which the belt touches,

$$\log. \frac{\mathrm{S}}{s} = fa° \times \cdot 00757\ 98686$$
$$= fa^c \times \cdot 00682\ 18818$$

will give the ratio of the tensions at its two extremities when the belt is slipping. For half a turn the difference of the logarithms is $f \times 1 \cdot 36437\ 63538$; and thus, if the friction between the two surfaces were equal to the pressure, the ratio between the tensions of the two ends of a belt bent half round any cylindroid would need to be 23 : 1 before the belt would begin to slip.

When we know the coefficient of friction and the angle of contact, we can compute, by the above formula, the ratio of the tensions; conversely, if we have obtained the ratio of the tensions by experiment, we can compute the coefficient of friction; or, lastly, having given the coefficient of friction, we can calculate the angular extent which may cause a given ratio between the tensions.

If, in the material used, the friction were one-fourth part of the pressure, and if a belt were thrown over a fixed pulley, as shown in Fig. 671, the logarithm of the ratio of the tensions would be $0 \cdot 3410941$, and the ratio itself would be $2 \cdot 19328 : 1$; so that if a weight of $2 \cdot 19$ lbs. were hung on at Q, a weight of 1 lb. at R would be sufficient to prevent it from falling, whereas it would take $4 \cdot 81$ lbs. at R to draw Q up. If the belt were thrown round so as to make the contact over three half-turns, the ratio of the strains would be the cube of the preceding, or $10 \cdot 5572$, so that 1 lb. at R would prevent the fall of 10 lbs. at Q.

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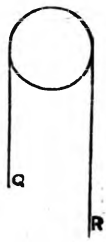


Hence the advantage which a sailor obtains by casting a line round a spar. With one turn he is able to resist a strain, say, four times that which he can exert directly; with another turn he squares the ratio and obtains an advantage of sixteen times; with a third turn an advantage of sixty-four times. In this way he is able to command the strain on the cable, so as by paying it out to stem gradually the motion of the ship. Hence also it is that one man pulling at the loose end of a rope can prevent it from slipping on a windlass at which several men are working.

Another example of the application of this law is as follows:—Having tied a weight to the end of a string, let us give the string a few turns round the smooth axis of a fly-wheel, and then pull at the free end. If the weight be, say, 1 lb., we may exert a strain of perhaps 60 lbs. without causing the cord to slip upon the axis: and by steadily continuing to pull, we put the fly-wheel in motion. But when we cease to pull, the force which the fly-wheel has acquired carries it forwards so as to raise the weight and relieve the tension of that end of the cord by which we hold. As soon as this tension is reduced to the sixtieth part of a pound, the cord slips, and, if we let back the string, the weight falls. In this way, by alternately pulling and letting down, we generate motion only in one direction, since the resistance downwards is but a small fraction of the pressure exerted upwards.

This rapid accumulation of resistance explains the actions of ties, splices, and knots of all kinds: the manner in which it takes place is, on that account, deserving of careful study.

Having now considered the elementary principles on which the action of the driving-belt is founded, E. Sang proceeds to the proper subject of his essay.

Let us suppose that, while a definite resistance is offered to the motion of the wheel B, the apparatus represented in Fig. 668 is actually turning, in consequence of a force communicated through the wheel A. The free part, G F, of the belt has been strained, and the part C D relaxed, until the difference between the two strains has become equal to the offered resistance. Thus at G the belt is lapped upon the driver in a distended state; but it cannot remain in this state until it reach C, for we have seen that any difference in tension between two parts of the belt can only exist in consequence of the friction on the intermediate surface. If the angular distance C H correspond to the ratio of the two tensions, the parts of the belt, as soon as they reach H, must begin to contract, and so fall behind the surface of the wheel in its onward progress; and this contraction must go on until each part arrive at C in that particular state of distension which is due to the strain on C D.

The belt, in its now contracted state, is applied at D to the surface of the pulley B, and proceeds along with that surface until it reaches a point E, having the angular distance E B F equal to H A C; there it begins to be distended, and it reaches F in a state to exert the tension on F G.

Thus it appears that in the ordinary and perfect action of a belt there is necessarily a slipping over the surfaces of the wheel and of the pulley; a slipping which is evinced by the polish and tear and wear of those surfaces. The ordinary notion that the velocity of the wheel should be just that of the belt is thus seen to be altogether erroneous, and the idea of communicating a determinate velocity by means of a belt to be quite a fallacy.

If, on account of increased resistance to the motion of B, the ratio of the tensions on F G and C D be augmented, the extent of the arcs of slipping must increase also; and as soon as the ratio becomes what is due to the arc D F, the belt will be drawn over the pulley without carrying it along, and then the belt slips in the ordinary acceptation. Now the angle of contact is greater on the larger wheel, and therefore we may be prepared to expect that the belt should slip on the pulley. With crossed belts the angles of contact are nearly alike on both surfaces, and minor circumstances are then sufficient to determine on which of the two the slipping will happen. Hence it is useful to arrange the machinery so that the curvature of the slack part of the belt may augment the angle of contact; in general, it is best to have the upper free part slack.

The remedy for the slipping is to augment the general tension of the belt either by increasing the distance between the centres or by shortening the belt; in some cases by using deflecting pulleys. These remedies would have been ineffectual if the angular distance C H had been proportional to the difference between the two tensions instead of to the difference between their logarithms; but as it is, when we augment equally both strains we diminish the ratio between them, and thus lessen the distance over which the slipping takes place, so as to bring it within F D.

In practice it is clearly advantageous to have the belt as slack as the nature of the work will permit, in order to have no avoidable strain and friction upon the axes. This arrangement is readily made by trial, and must, indeed, be repeatedly performed in consequence of the permanent elongation which takes place in new belts; nevertheless, in order to leave no essential part of the theory untouched, we propose to compute the actual quantity of belt which must be used to overcome a stated resistance.

From the dimensions of the machinery we can easily ascertain the angle D B F, and from that, if the coefficient of friction be known, the utmost ratio that can be allowed between the strains on the two free parts of the belt. The nature of the work to be done gives us the difference between those strains, and thus, by the solution of a very easy equation, we can compute the strains themselves.

If $d$ be the required difference, and if $\rho$ be the ratio of the two strains, we must have

$$S = \frac{\rho\, d}{\rho - 1}; \quad s = \frac{d}{\rho - 1},$$

where, according to what has been already shown, $\rho = e^{f(\mathrm{D\,B\,F})}$.

Having now ascertained the values of the strains to which the two parts of the belt must be subjected, we can discover how much belt must be used by attending to the law of its extension. Having suspended a piece of it by one end, and measured the distance between two marks made on it, we attach a known weight to the lower end, and measure the increased distance between the same marks. By this experiment we discover the law of distension of all belts of the same material. Let $x$ be the extension of one unit in length when its own weight is hung on; then if $w$ be the weight per foot of another belt of the same material, $l$ its length when unstrained, and $s$ the strain to which it is subjected, its length on being strained becomes $l\left(1 + \frac{x}{w}\, s\right)$.

For ordinary practice it is sufficient to suppose that the whole length of the belt is subjected to the average of the two strains, S and $s$, so that if Q be the quantity of belt, that is, the length measured when there is no tension, and L the true length of the line C D E F G H,

$$L = Q\left(1 + x\,\frac{S + s}{2\,w}\right); \quad Q = \frac{2\,w\,L}{2\,w + x\,(S + s)}.$$

When the material is not very extensile, the quantity of extension, or the distance which the two ends should want of meeting before they are joined together, is given to a sufficient degree of precision by the formula, $L - Q = L\,\frac{x}{w}\,\frac{S + s}{2}$, from which we see that the distension of the band is nearly proportional to the strain on the axes.

This computation is, however, only approximate. If we wish to obtain a true result we must look more narrowly into the conditions of the problem; and although, for practical purposes, this be a mere refinement of exactitude, it is yet useful in leading to a just perception of the principles involved.

Let C be the distance between the centres, R and $r$ the radii of the two wheels, and $i$ the inclination of each free part of the belt to the straight line joining the centres: then in the case of the plain belt we have

$$\begin{aligned} R - r &= C \sin. i, \\ C D &= a \cos. i, \\ D F &= r(\pi - 2i), \\ G C &= R(\pi + 2i), \end{aligned}$$

so that the entire length of the belt, taking no account of the deviation from straightness caused by its own weight, is $L = 2C \cos. i + \pi(R + r) + 2i(R - r)$.

The belt is in various states of tension at different places. From C to D there is the uniform tension $s$; from D the tension gradually increases to F, where it becomes equal to S; from F to G the tension remains constant, nor does it begin to change until we reach the point $h$, so taken that the angular distance C $h$ is equal to D F; at that point the tension begins to decrease, until it is reduced to S at the point C. These are the phases when the belt is plain and when the larger wheel drives.

Putting $k$ for $\frac{x}{w}$, that is, for the extensibility of the actual belt, the quantities on the two free parts C D and F G are $\frac{a \cos. i}{1 + ks}$ and $\frac{a \cos. i}{1 + kS}$; the length of the arc G $h$ is L, $4Ri$, and since the tension on it is S, when the larger wheel drives, the quantity of belt is $\frac{4Ri}{1 + KS}$.

There remain yet to be computed the quantities of belt on the two arcs D F and $hc$, over which the tension is variable. Since these are similar arcs of different circles, and since the gradation of strain is alike in both, the quantities of belt on them must be proportional to their radii, and so one investigation is enough.

Let, then, $\theta$ be an arc over which the tension varies, and let $d\theta$ be an element of that arc, the radius being unit; then if $s$ be the strain at the beginning, $s\epsilon^{f\theta}$ is the strain at the end of the arc, and the quantity of belt applied to $d\theta$ is $dq = d\theta(1 + k\epsilon^{f\theta}s)^{-1}$.

The integral of this gives the quantity of belt on the whole arc $s$ to be

$$q = \theta + \frac{1}{f} \log._\epsilon \frac{1 + ks}{1 + ksc^{f\theta}}.$$

To adapt this general formula to our present case, we must put $\theta = \pi - 2i$, and observe that then $s\epsilon^{f\theta}$ becomes the major strain S, so that $(R + r)\left\{\pi - 2i + \frac{1}{f} \log._\epsilon \frac{1 + ks}{1 + kS}\right\}$ is the quantity of belt covering these two arcs. Hence the length of the entire belt in its unstretched state must, in order to give the requisite strain, be

$$Q = a \cos. i\left(\frac{1}{1 + ks} + \frac{1}{1 + kS}\right) + \frac{4iR}{1 + kS} + (R + r)\left(\pi - 2i - \frac{1}{f} \log._\epsilon \frac{1 + kS}{1 + ks}\right),$$

and the amount of contraction when the belt is taken off the wheels should be

$$L - Q = a \cos. i\left(\frac{ks}{1 + ks} + \frac{kS}{1 + ks}\right) + 4iR \frac{kS}{1 + kS} + \frac{R + r}{f} \log._\epsilon \frac{1 + kS}{1 + ks}.$$

When the smaller wheel leads the larger, the tension on the arc G $h$ is only $s$, and the above formula becomes

$$L - Q^1 = a \cos. i\left(\frac{ks}{1 + ks} + \frac{kS}{1 + kS}\right) + 4iR \frac{ks}{1 + ks} + \frac{1}{f}(R + r) \log._\epsilon \frac{1 + kS}{1 + ks}.$$

And, when the belt is crossed, we have $a \sin. i' = R + r$, and the angles of contact, $\pi + 2i'$ each, the point, $h$, merging into G; hence the entire length in that case is

$$L' = 2a \cos. i' + (R + r)(\pi + 2i'),$$

and the amount of distension, $L' - Q'' = \cos. i'\left(\frac{ks}{1 + ks} + \frac{kS}{1 + kS}\right) + (R + r)\frac{1}{f} \log._\epsilon \frac{1 + kS}{1 + ks}$.

If we develop the above values of the contraction in series, according to the powers of $k$, and omit the second and higher powers, which are always exceedingly small fractions, we obtain the approximations,

$$L - Q = k\left\{a \cos. i(S + s) + 4RiS + \frac{1}{f}(R + r)(S - s)\right\}$$

$$L - Q' = k\left\{a \cos. i(S + s) + 4Ris + \frac{1}{f}(R + r)(S - s)\right\}$$

$$L' - Q'' = k\left\{a \cos. i'(S + s) + 4Ris + \frac{1}{f}(R + r)(S - s)\right\}$$

The last term of each of these expressions depends on $S - s$, that is, on the work to be done, while the first terms depend on the manner in which that work is accomplished.

Throughout the whole of these inquiries, the superiority of the crossed belt is apparent. Thus, in plain belts the ratio of S to $s$ is much less than in crossed belts, and therefore the general tension and consequent friction must be greater.

Having now examined what may be called the statical part of our subject, and ascertained the relation between the resistance to be overcome and the length of the belt, Sang proceeds to consider those phenomena which attend the continuous motion of the apparatus.

It at once follows, from the continuity of the belt, that if the resistance remain unchanged, equal quantities must pass over with the circumference of both wheels. Now it is wrapped upon the driving in a more distended state than upon the driven wheel, so that the linear velocity of the latter must be less than that of the former. If B be the entire *quantity* of belt which has passed a given point, the distances traversed by the driving and driven wheels must have been $B(1 + kS)$ and $B(1 + ks)$ respectively. Now the force, or quantity of work done, is the product of the resistance by the distance passed over; so that the force given out by the driver must have been $B(S - s)(1 + kS)$, while that communicated to the pulley has only been $B(S - s)(1 + ks)$. Hence a belt does not transmit the whole of the force delivered to it. The origin and nature of this loss have not, so far as I am aware, ever been adverted to, and on this account I shall examine it the more minutely.

Subtracting the second expression from the first, and replacing for $k$ its equivalent $\frac{x}{w}$, we have

loss of force $= B\,\frac{x}{w}(S - s)^2$.

From this it appears that the loss of force is directly proportional to the extensibility of the material of the belt, and inversely to the weight of a given length of it: and hence the advantage of using a material not easily stretched, and also, with a limitation to be hereafter noticed, heavy rather than light belts.

Again, if we have to create a given tension, we may, by augmenting the diameters of both wheels proportionally, reduce $S - s$; for example, with double diameters we should have $S - s$ halved, and its square quartered; but then the belt would pass with double speed: so that, taking all into account, the loss of force would be halved, provided the strength of the belt be not changed. Hence we have these maxims:—

The loss of force is directly proportional to the specific extensibility of the material, inversely proportional to the weight of one foot of the belt, and also inversely proportional to the diameters of the wheels when their ratio and the work to be done are fixed.

The only absorbent of this lost force is the friction of the belt upon the surfaces of the two wheels. In order to compute the amount of this friction, let $\sigma$ be the strain at any part of the arc over which the slipping takes place, and $\frac{B}{\tau}$ the quantitative velocity of the belt, then $\frac{B}{\tau}(1 + k\sigma)$ is the linear velocity of that part of the belt, while $\frac{B}{\tau}(1 + kS)$ is the velocity of the surface of the wheel; so that the rate of slipping must be $\frac{B}{\tau}k(S - \sigma)$. Now the friction on an element of the arc is necessarily $d\sigma$, so that $\frac{B}{\tau}k(S - \sigma)\,d\sigma$ is the rate at which force is absorbed by friction upon this element. Integrating from $\sigma = S$ to $\sigma = s$, and extending the computation over the whole time, the force lost by friction on the wheel is $\frac{1}{2}Bk(S - s)^2$: that consumed by friction on the pulley is also $\frac{1}{2}Bk(S - s)^2$; and thus the total loss is $Bk(S - s)^2$, precisely what we found by comparing the velocities of the two wheels. We may observe here that the same result would have been found although any other law of friction or of extensibility had been assumed; and it is also worthy of notice that this force has been distributed equally between the two wheels, irrespective of their diameters.

The amount of force delivered to the driver is $(S - s)(1 + ks)B$, but the whole of this is not communicated to the free parts of the belt, a portion $(S - s)\frac{1}{2}Bk$ being previously absorbed by friction on the surface of the driver. The force received by the free parts of the belt, and by them transmitted to the pulley, is thus, $B(S - s)\left\{1 + k\frac{S + s}{2}\right\}$. Of this, again, a second portion $\frac{1}{2}Bk(S - s)$ is intercepted by the friction on the surface, and only $B(S - s)(1 + ks)$ communicated to the shaft of the pulley.

In the above formula, for the force actually transmitted along the free parts of the belt, we may observe that the last factor is, for all practical purposes, a constant quantity for a given belt when once put on; for although the apparatus may encounter a variety of resistances, $S - s$, the sum of the two tensions, S and $s$, hardly varies.

Now the distances passed over by the circumferences of the two wheels are susceptible of easy measurement; let us suppose that, in the time $\tau$, these distances have been found to be D and $d$; then we shall have $D = B(1 + kS)$; $d = B(1 + ks)$; whence

$$S - s = \frac{D - d}{Bk};\quad B\left(1 + k\frac{S + s}{2}\right) = \frac{D + d}{2};$$

so that the force transmitted through the free parts of the belt is $\frac{D - d}{k} \cdot \frac{D + d}{2B}$.

In perfect strictness this formula is only true if the tensions remain uniform during the whole time, for the last factor $\frac{D + d}{2B}$ varies slightly with the resistance to be overcome. In practice,

however, this factor scarcely differs from $\frac{L}{Q}$, and the error of substituting this latter for it is contained within very narrow and ascertainable limits; hence we may assume, for all practical purposes, the formula

$$\text{Transmitted force} = (D - d)\frac{L}{Q} \cdot \frac{w}{x},$$

as giving the amount of force transmitted during the time over which the measurements extend.

The entire loss of force in the same time is $2\frac{(D-d)^2}{D+d}\frac{L}{Q}\frac{w}{x}$, one-half being lost at each surface.

Knowing, then, the specific extensibility of the material which is denoted by $x$, and $w$ the weight of a linear unit of the belt used, we are prepared to register the amount of force actually transmitted by it. For this purpose, we bring the edges of two light pulleys to bear gently upon the two free parts of the belt, so as to register the distances through which they move, and then the differences between these distances is proportional to the transmitted force.

Even although the belt be not quite uniform in thickness, this method of registration still answers, particularly if the values of $x$ and $w$ be determined by experiments made on the whole length of the actual belt.

Hitherto we have reasoned as if the belt had no thickness, as if the surfaces of the pulleys were truly cylindric, and as if the material were perfectly elastic. We have yet to take all these circumstances into account.

For the purpose of obviating the tendency which a flat belt has to run off the pulleys, the surfaces of these are made convex in the direction of the axis. At first thought it would appear that such a form would increase the tendency to run off, and that a grooved or hollow contour would rather be needed; but a little reflection clears the matter up. When a band of rope or of ox-gut is used, the wheels are made with deep grooves; in these cases the roundness of the band allows it to roll, so to speak, down the declivity of the groove whenever the inaccurate position of the wheels has tended to lead it out of its proper place. The spiral motion resulting from this action is familiar to turners. Since the pressure upon the sides of the groove is augmented in proportion to the cosecant of the half angle, the friction is augmented in the same proportion, and hence deep angular grooves give a better hold to the band, and enable the lathe to run more lightly than round-bottomed grooves do.

But when a flat belt is used, this rolling cannot take place, and the adhesion of the surfaces causes an action which may be best explained by help of a simple mechanical illustration.

Having provided a slightly tapered cone A B C D, let a belt E F be attached to its surface in a direction perpendicular to the axis; and then let the cone be turned gently round while the tape E F, with a strain upon it, is obliged to pass through a fixed aperture at F. That side of the belt which is toward the larger end of the cone is more rapidly taken up than the other side, and the belt, in consequence, gradually inclining from the perpendicular, runs up toward the thicker end of the cone until the obliquity of the strain directed to F causes it to slide.

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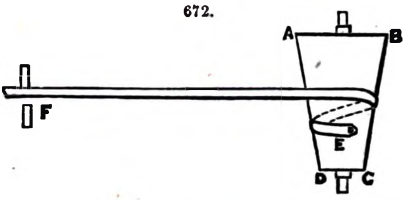



If the surfaces of the wheels were truly cylindric, and exactly opposite to each other on parallel shafts, and if the belt were perfectly straight and uniform, there would be no tendency to move to the one side or to the other. But belts, and especially those of leather, are liable to irregularities, and their joints are with difficulty made straight, so that the two edges are not of equal length: besides, we are unable to arrange machinery with perfect accuracy; hence arises a tendency of the belt to move aside: this tendency is corrected by the rounding of the peripheries. The effect of this rounding is easily seen. Whenever the belt has chanced to go to one side, that edge which is nearer the middle of the pulley is taken up faster than the other edge, and so the belt is soon brought into its place again. It may be here observed that this very provision which keeps the belt in its place so long as the machinery is in proper action, tends to throw it off whenever the resistance becomes so great as to cause a slipping. The degree of rounding of the rims depends on the character of the belts, and on the precision with which the machinery is erected; it can, therefore, only be ascertained by experience. The rounding should be made as slight as is consistent with security, since, as we shall see immediately, every deviation from the cylindric form is accompanied by a loss of force.

In their progress round the wheels, the different parts of the belt are stretched and relaxed alternately. Now, if the material were perfectly elastic, the force expended on the distension would be reproduced on the contraction of the belt; but the imperfection of the elasticity prevents more than a portion of this force from being restored, and hence arises a loss, the character and amount of which we may attempt to examine.

There do not exist any series of experiments on the phenomena of imperfect elasticity of sufficient extent or exactitude to make known the law according to which force is lost by it. Analogy and a few experiments have led to the belief that, within the limits of ordinary practice, the force reproduced bears to that which had been expended in disturbing the natural condition of the particles a ratio constant for a given material; but observations that we have lately made have satisfied us that this law is far from being true, and that *time* has a great influence on the phenomena. For the present, it will be enough to observe that the loss of force will certainly be greater the greater the disturbance of the particles.

Now, in changing from the state of tension S to that of $s$, the amount of linear disturbance is

proportional inversely to the weight, $w$, of a given length of the belt, and therefore, in respect of this part of the action also, the loss of force is the less the heavier the belt is made. So far as we have yet seen, it is preferable to use heavy belts.

When bent round the circumference of a wheel, the outer parts of the belt are distended, the inner parts relaxed; and supposing the section of the belt to be rectangular, the amount of force expended in making these changes is proportional directly to the breadth, to the square of the thickness, and inversely to the diameter of the wheel. Hence if two belts be of like strength, but the one broad and thin, the other narrow and thick, the amounts of force expended in bending them must be proportional directly to their thicknesses; and hence the advantage of using broad thin belts.

The practice of strengthening belts by riveting on an additional layer must be exceedingly objectionable; indeed, it is difficult to see how any additional strength is gained, for the outer layer must be tight when on the wheel, and slack when free; so that, in reality, the strength of only one layer can be available: the parts of the compound belt are puckered and open alternately, as evinced by the crackling noise. The proper procedure is to increase the breadth of the belt.

If, as must be the case in all driving-belts, the rim of the wheel be rounded, the loss of force by flexure is augmented; because the difference between the radii of the middle of the outer surface, and of the edge of the inner surface, is greater than if the rim had been cylindric; and hence the importance of having the rims as little rounded as possible.

If the law of imperfect elasticity were known, we could reduce these various losses to calculation; as it is, we can only take a limited and very unsatisfactory view of the subject.

The following investigation was undertaken by J. B. Francis, for the Merrimack Manufacturing Company, of Mass., U.S., for the purpose of determining the relative fitness of shafting and belting, of particular materials, for a cotton factory being erected by this company.

In factories and workshops, power is usually taken off from the lines of shafting, at many points, by pulleys and belts, by means of which the machinery is operated, as shown in Figs. 664, 665. When the machines to be driven are below the shaft, there is a transverse strain on the shaft, due to the weight of the pulley and tension of the belt, which is in addition to the transverse strain due to the weight of the shaft itself. Sometimes the power is taken off horizontally on one side, in which case the tension of the belt produces a horizontal transverse strain; and the weight of the pulley acts with the weight of the shaft to produce a vertical transverse strain. Frequently the machinery to be driven is placed above the floor to which the shaft is hung in the story below; in this case the transverse strain produced by the tension of the belt is in the opposite direction to that produced by the weight of the pulley and shaft. Sometimes power is taken off in all these directions from the part of a shaft between two adjacent bearings. To transmit the same power, the necessary tension of a belt diminishes in proportion to its velocity; consequently, with pulleys of the same diameter, the transverse strain will diminish in the same ratio as the velocity of the shaft increases. In cotton and woollen factories with wooden floors the bearings are usually hung on the beams, which are usually about eight feet apart; and a minimum size of shafting is adopted for the different classes of machinery, which has been determined by experience as the least that will withstand the transverse strain. This minimum is adopted independently of the size required to withstand the torsional strain due to the power transmitted; if this requires a larger diameter than the minimum, the larger diameter is, of course, adopted. In some of the large cotton factories in this neighbourhood, in which the bearings are about 8 ft. apart, a minimum diameter of $1\frac{7}{8}$ in. was formerly adopted for the lines of shafting driving looms. In some mills this is still retained, in others $2\frac{1}{8}$ in. and $2\frac{3}{16}$ in. have been substituted. In the same mills the minimum size of shafts driving spinning machinery is from $2\frac{1}{8}$ to $2\frac{1}{16}$ in. In very long lines of small shafting fly-wheels are put on at intervals, to diminish the vibratory action due to the irregularities in the torsional strain.

We can deduce from formula [1], which will be presently established, the *breaking power*, or, in other words, the power which, being transmitted by a shaft, will produce a torsional strain upon it equal to its total resistance to that force.

Put $p$ = the breaking power, in horse-powers of 33,000 foot-pounds.

$\mathrm{N}$ = the number of revolutions of the shaft per minute.

$$p = \frac{2\pi \mathrm{R N W}}{12 \times 33000},$$

from which we deduce,

$$\mathrm{W R} = \frac{12 \times 33000\, p}{2\pi \mathrm{N}}.$$

Substituting this value in [1], we find,

$$p = \frac{\pi^2 \mathrm{N}\, d^3\, \mathrm{T}}{8 \times 33000 \times 12} = 0{\cdot}000003115\, \mathrm{N}\, d^3\, \mathrm{T}. \qquad [8]$$

Substituting the values of T, adopted above for iron and steel, we have

For wrought iron, $p = 0{\cdot}1558\, \mathrm{N}\, d^3$, [9]

„ steel, $p = 0{\cdot}2492\, \mathrm{N}\, d^3$, [10]

„ cast iron, $p = 0{\cdot}0935\, \mathrm{N}\, d^3$. [11]

A formula for the wrought-iron shafts of prime movers and other shafts of the same material, subject to the action of gears, which Francis adopted in numerous cases in practice during the last twenty years, and found to give an ample margin of strength, is

$$d = \sqrt[3]{\frac{100\, \mathrm{P}}{\mathrm{N}}}, \qquad [12]$$

in which P = the power transmitted, and from which we deduce

$$P = 0{\cdot}01\,N\,d^3. \qquad [13]$$

For simply transmitting power, the formula used is

$$d = \sqrt[3]{\frac{50\,P}{N}}, \qquad [14]$$

from which we deduce

$$P = 0{\cdot}02\,N\,d^3. \qquad [15]$$

The following Table gives the power which can be safely carried by shafts making 100 revolutions per minute. The power which can be carried by the same shafts at any other velocity may be found by the following simple rule:—

*Multiply the power given in the Table by the number of revolutions made by the shaft a minute; divide the product by* 100; *the quotient will be the power which can be safely carried.*

| Diameter in Inches. | Horse-power which can be safely carried by Shafts for Prime Movers and Gears, well supported by bearings, and making 100 revolutions a minute; if of | | | Horse-power which can be safely transmitted by Shafts making 100 revolutions a minute, in which the Transverse Strain, if any, need not be considered; if of | | |
|---|---|---|---|---|---|---|
| | Wrought Iron, computed by Formula [13] | Steel, computed by Formula [16]. | Cast Iron, computed by Formula [20]. | Wrought Iron, computed by Formula [15]. | Steel, computed by Formula [18]. | Cast Iron, computed by Formula [22]. |
| 1·00 | 1·00 | 1·60 | 0·60 | 2·00 | 3·20 | 1·20 |
| 1·25 | 1·95 | 3·12 | 1·17 | 3·90 | 6·24 | 2·34 |
| 1·50 | 3·37 | 5·39 | 2·03 | 6·74 | 10·78 | 4·06 |
| 1·75 | 5·36 | 8·58 | 3·22 | 10·72 | 17·16 | 6·44 |
| 2·00 | 8·00 | 12·80 | 4·80 | 16·00 | 25·60 | 9·60 |
| 2·25 | 11·39 | 18·22 | 6·83 | 22·78 | 36·44 | 13·66 |
| 2·50 | 15·62 | 24·99 | 9·37 | 31·24 | 49·98 | 18·74 |
| 2·75 | 20·80 | 33·28 | 12·48 | 41·60 | 66·56 | 24·96 |
| 3·00 | 27·00 | 43·20 | 16·20 | 54·00 | 86·40 | 32·40 |
| 3·25 | 34·33 | 54·93 | 20·60 | 68·66 | 109·86 | 41·20 |
| 3·50 | 42·87 | 68·59 | 25·72 | 85·74 | 137·18 | 51·44 |
| 3·75 | 52·73 | 84·37 | 31·64 | 105·46 | 168·74 | 63·28 |
| 4·00 | 64·00 | 102·40 | 38·40 | 128·00 | 204·80 | 76·80 |
| 4·25 | 76·77 | 122·83 | 46·06 | 153·54 | 245·66 | 92·12 |
| 4·50 | 91·12 | 145·79 | 54·67 | 182·24 | 291·58 | 109·34 |
| 4·75 | 107·17 | 171·47 | 64·30 | 214·34 | 342·94 | 128·60 |
| 5·00 | 125·00 | 200·00 | 75·00 | 250·00 | 400·00 | 150·00 |
| 5·25 | 144·70 | 231·52 | 86·82 | 289·40 | 463·04 | 173·64 |
| 5·50 | 166·37 | 266·19 | 99·82 | 332·74 | 532·38 | 199·64 |
| 5·75 | 190·11 | 304·18 | 114·06 | 380·22 | 608·36 | 228·12 |
| 6·00 | 216·00 | 345·60 | 129·60 | 432·00 | 691·20 | 259·20 |
| 6·25 | 244·14 | 390·62 | 146·49 | 488·28 | 781·24 | 292·98 |
| 6·50 | 274·62 | 439·39 | 164·78 | 549·24 | 878·78 | 329·56 |
| 6·75 | 307·55 | 492·08 | 184·53 | 615·10 | 984·16 | 369·06 |
| 7·00 | 343·00 | 548·80 | 205·80 | 686·00 | 1097·60 | 411·60 |
| 7·25 | 381·08 | 609·73 | 228·65 | 762·16 | 1219·46 | 457·30 |
| 7·50 | 421·87 | 674·99 | 253·13 | 843·74 | 1349·98 | 506·26 |
| 7·75 | 465·48 | 744·77 | 279·29 | 930·96 | 1489·54 | 558·58 |
| 8·00 | 512·00 | 819·20 | 307·20 | 1024·00 | 1638·40 | 614·40 |
| 8·25 | 561·52 | 898·43 | 336·91 | 1123·04 | 1796·86 | 673·82 |
| 8·50 | 614·12 | 982·59 | 368·47 | 1228·24 | 1965·18 | 736·94 |
| 8·75 | 669·92 | 1071·87 | 401·95 | 1339·84 | 2143·74 | 803·90 |
| 9·00 | 729·00 | 1166·40 | 437·40 | 1458·00 | 2332·80 | 874·80 |
| 9·25 | 791·45 | 1266·32 | 474·87 | 1582·90 | 2532·64 | 949·74 |
| 9·50 | 857·37 | 1371·79 | 514·43 | 1714·74 | 2743·58 | 1028·86 |
| 9·75 | 926·86 | 1482·98 | 556·12 | 1853·72 | 2965·96 | 1112·24 |
| 10·00 | 1000·00 | 1600·00 | 600·00 | 2000·00 | 3200·00 | 1200·00 |

Comparing formula [9] with [12] and [13], and also with [14] and [15], it will be seen that the formulas [12] and [13], used for shafts for prime movers, give a strength 15·58 times the breaking power; and the formulas [14] and [15], for shafts simply transmitting power, give a strength 7·79 times the breaking power.

In applying the rules for the strength of materials to constructions in which there is no move-

ment, it is usual to make the computed strength from three to five times the breaking strain. Bodies in rapid motion, however, usually require a greater margin of strength, in order to provide for the tendency to vibration. In cases where shafting for simply transmitting power is very accurately finished, and firmly supported by bearings at short intervals, an excess of strength two-thirds of that given by formulas [14], [19], and [23], will undoubtedly suffice. In ordinary cases, however, the strength given by these formulas should be adopted.

It must be understood that the shafts to which formulas [12] and [13] are applied, are supported by bearings sufficiently near to each other to guard against the transverse strain caused by the prime mover or gear.

To find formulas for steel shafts of the same strength as those for wrought iron, we have for prime movers $p = 15{\cdot}58\,\mathrm{P}$: substituting this value of $p$ in [10], we have

$$\mathrm{P} = 0{\cdot}016\,\mathrm{N}\,d^3, \qquad [16]$$

from which we deduce

$$d = \sqrt[3]{\frac{62{\cdot}5\,\mathrm{P}}{\mathrm{N}}}. \qquad [17]$$

Similarly, we find for steel shafts for simply transmitting power,

$$\mathrm{P} = 0{\cdot}032\,\mathrm{N}\,d^3, \qquad [18]$$

and

$$d = \sqrt[3]{\frac{31{\cdot}25\,\mathrm{P}}{\mathrm{N}}}. \qquad [19]$$

Similarly, for cast iron, we find for prime movers,

$$\mathrm{P} = 0{\cdot}006\,\mathrm{N}\,d^3, \qquad [20]$$

$$d = \sqrt[3]{\frac{167\,\mathrm{P}}{\mathrm{N}}}. \qquad [21]$$

For simply transmitting power,

$$\mathrm{P} = 0{\cdot}012\,\mathrm{N}\,d^3, \qquad [22]$$

$$d = \sqrt[3]{\frac{83\,\mathrm{P}}{\mathrm{N}}}. \qquad [23]$$

Comparing formulas [14] and [19], it will be seen that the diameters of shafts of wrought iron and steel to transmit the same power are in the ratio of the cube root of 50 to the cube root of 31·25, or as 1 to 0·855. The weights of the shafts will be as the squares of the diameters, or as 1 to 0·731. The power required to overcome the friction of the shafts in their bearings, assuming that the coefficient of friction is the same for wrought iron and steel, will be as the products of the weights into the velocities of the rubbing surfaces. The number of revolutions in a given time being the same in both, the velocities of the rubbing surfaces will be as the diameters, and the weights will be as the squares of the diameters; the power required to overcome the friction will therefore be as the cubes of the diameters, or as 1 to 0·625. That is to say, the power which must be expended to overcome the friction of a steel shaft is five-eighths of that required to overcome the friction of a wrought-iron shaft of equal strength.

The superiority of steel to resist transversal strain is much less than to resist torsional strain. The relative diameters of wrought-iron and steel shafts, to resist equal transverse strains, exclusive of their own weights, are inversely as the fourth roots of the respective values of E, or as $\left(\frac{1}{3500000}\right)^{\frac{1}{4}}$ to $\left(\frac{1}{3800000}\right)^{\frac{1}{4}}$, or as 1 to 0·98. That is to say, steel shafts, to offer the same resistance to external transverse strains, may be 2 per cent. less in diameter than wrought-iron shafts. The weights of such steel shafts will be about 4 per cent. less than the weights of wrought-iron shafts of equal stiffness; and the power required to overcome the friction of the bearings will be about 6 per cent. less.

The constant expressing the resistance of cylindrical bars to torsion, is deduced from Navier's formula (see 'Résumé des Leçons sur l'Application de la Mécanique'),

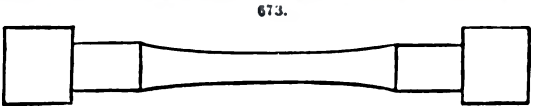
$$\mathrm{T} = \frac{16\,\mathrm{W}\,\mathrm{R}}{\pi\,d^3}, \qquad [1]$$

in which,

T = a constant for the same material.
W = the weight, in pounds, which, if applied at the distance R, in inches, from the axis, will just fracture the bar.
$\pi$ = the ratio of the circumference of a circle to its diameter.
$d$ = the diameter, in inches, of the bar at the place of fracture.

The bars subjected to torsion were finished in the form of the following diagram; the ends being 2 in. square, and the middle turned down to a diameter of $\frac{3}{4}$ in., in order to ensure the fracture taking place in that part of the bar.

673.



The weight producing the torsion was applied at the end of a lever, of the effective length of 35·975 in., fitted to the square boss at one end of the bar.

The tendency of the bar to revolve under the action of the weight, was controlled by a worm-wheel about 15 in. in diameter and 138 teeth, fitted to the square boss at the other end of the bar. This wheel could be moved through any arc by means of a worm. As the bar became twisted by the torsional strain, the worm-wheel was moved through an arc sufficient to bring the lever to an horizontal position.

A graduated circle on one face of the worm-wheel furnished the means of measuring the arc of torsion.

The effective weight of the lever and scale at 35·975 in. from the axis, where the scale was hung on a knife-edge, was 48·5 lbs., and was the least effective weight which could be applied to produce torsion.

EXPERIMENTS ON TORSION.

| Description of the Bar. | Mean Diameter of the reduced part of the Bar, in inches. | Arc of Torsion just before Fracture. | Weight producing Fracture, in pounds. | Mean Temperature of the Air. | Value of T. |
|---|---|---|---|---|---|
| English refined wrought iron, from a bar 2 in. in diameter, marked A, 13 | 0·750 | 416°·8 | 113·17 | 58°·8 | 49,148 |
| Same, marked 13 | 0·750 | 596·0 | 125·69 | 66·0 | 54,585 |
| Wrought iron, from the Pembroke Iron Works, Maine, marked 14 | 0·753 | 641·3 | 143·72 | 62·3 | 61,673 |
| Decarbonized steel, from the Farist Steel Company, Windsor Locks, Conn., from a bar 2 in. square, marked B, 6 | 0·752 | 390·5 | 192·48 | 70·2 | 82,926 |
| Spindle steel, from the same, from a bar 2 in. square, marked A, 5 | 0·750 | 284·3 | 235·17 | 68·3 | 102,131 |
| Steel, from the Nashua Iron Company, Nashua, N.H., from a bar 2 in. square, marked 2 | 0·751 | 611·3 | 198·73 | 65·5 | 85,961 |
| Same, marked *d*, 2 | 0·752 | 557·0 | 203·23 | 63·7 | 87,557 |
| Steel, from same, from 1¼ in. octagonal bar, marked 4 | 0·752 | 475·0 | 221·0 | 67·5 | 95,213 |
| Same, marked 3 | 0·751 | 508·3 | 217·25 | 61·2 | 93,972 |
| Steel, from the works of Hussey, Wells, and Co., Pittsburgh, from a bar 2 in. square, marked E, 1 | 0·751 | 308·0 | 202·66 | 63·6 | 87,661 |
| Same, marked 1 | 0·748 | 297·3 | 196·50 | 68·0 | 86,023 |
| Bessemer steel, from the works of Messrs. Winslow and Griswold, Troy, New York, from a bar 2 in. square, marked 16 | 0·748 | 215·5 | 181·97 | 66·0 | 79,662 |
| Same, marked 16 x | 0·748 | 268·5 | 174·50 | 67·0 | 76,392 |

EXPERIMENTS ON DEFLECTION.

| Description of the Bar. | Diameter of Bar at the middle, in inches. | Deflection, in inches. | Mean Temperature of the Air. | Value of E. |
|---|---|---|---|---|
| Spindle steel, from the Farist Steel Company, Windsor Locks, Conn., from a bar 1 1/16 in. in diameter, marked A, 7 | 0·995 | 0·2330 | 48°·0 | 3,853,590 |
| Same, marked A x 7 | 0·977 | 0·2315 | 53·8 | 3,847,530 |
| Decarbonized steel, extra, from the Farist Steel Company, from a bar 1 1/16 in. in diameter, marked A A x | 0·993 | 0·2310 | 53·0 | 3,918,360 |
| Same, marked A A 8 | 0·995 | 0·2327 | 53·7 | 3,858,557 |
| Decarbonized steel, from the Farist Steel Company, from a bar 1 1/16 in. in diameter, marked 9 x B | 0·992 | 0·2330 | 54·2 | 3,900,420 |
| Same, marked 9 B | 0·995 | 0·2307 | 53·3 | 3,892,008 |
| Steel, from the works of Hussey, Wells, and Co., Pittsburgh, from a bar 1 1/16 in. in diameter, marked 15 | 0·998 | 0·2337 | 52·2 | 3,796,060 |
| Same, marked 15 x | 0·996 | 0·2337 | 49·8 | 3,826,641 |
| Bessemer steel, from the works of Messrs. Winslow and Griswold, Troy, New York, from a bar 1 1/16 in. in diameter, marked 17 x | 1·000 | 0·2330 | 49·4 | 3,777,095 |
| Same, marked 17 | 1·000 | 0·2315 | 52·0 | 3,801,566 |

The experiments on deflection were made on round bars turned to a diameter of about 1 in. The distance between the points of support was 48 in. Observations were made of the deflections produced by a weight of 150 lbs. suspended at the middle point between the supports. This weight was not sufficient to cause any sensible set in the bar after the weight was removed; and no sensible increase in the deflection was produced by allowing the weight to remain suspended on the bar for several days.

The constant E for deflection has been computed by Navier's formula,

$$s = \frac{l^3 W}{6 \pi d^4 E}, \qquad [2]$$

in which

$l$ = the distance between the points of support, in inches.
W = the weight at the middle point between the supports, in pounds.
$\pi$ = the ratio of the circumference of a circle to its diameter.
$d$ = the diameter of the bar, in inches.
$s$ = the deflection at the middle point between the supports, in inches.

Several specimens of the steel have been tested for tensile strength, at the works of the South Boston Iron Company, by F. Alger, in the apparatus designed by Major W. Wade, for testing metals for cannon, a description of which may be found in 'Reports of Experiments on the Strength and other Properties of Metals for Cannon,' published in 1854, by authority of the Secretary of War, U.S.

EXPERIMENTS ON TENSILE STRENGTH.

| Description of the Specimen. | Diameter at the place of Fracture, in inches. | Weight producing Fracture, in pounds. | Tensile Strength a square inch, in pounds. | Specific Gravity |
|---|---|---|---|---|
| Spindle steel, from the Farist Steel Company, Windsor Locks, Conn., marked A 10 A 1 .. .. | 0·597 | 40,800 | 145,754 | 7·8401 |
| Same, marked A 10 A 2 .. .. .. .. .. .. | 0·598 | 39,500 | 140,639 | 7·8287 |
| Decarbonized steel, from the same, marked B 11 B 1 .. .. .. .. .. .. .. .. .. .. .. | 0·596 | 34,500 | 123,662 | 7·8583 |
| Same, marked B 11 B 2 .. .. .. .. .. .. | 0·597 | 35,200 | 125,750 | 7·8514 |
| Decarbonized steel, extra, from the same, marked A A x 1 .. .. .. .. .. .. .. .. .. .. | 0·600 | 30,500 | 107,862 | 7·8417 |
| Same, marked A A x 2 .. .. .. .. .. .. | 0·600 | 30,900 | 109,271 | 7·8579 |
| Same, marked A A x; ends upset in order to form the specimen .. .. .. .. .. .. .. .. .. | 0·600 | 30,800 | 108,901 | 7·8484 |
| Same as next preceding specimen, marked A A x 2 | 0·600 | 29,700 | 105,053 | 7·8534 |
| Steel, from the works of Hussey, Wells, and Co., Pittsburgh, marked c 12, 1 .. .. .. .. .. | 0·594 | 40,400 | 145,790 | 7·8530 |
| Same, marked c 12, 2 .. .. .. .. .. .. | 0·594 | 40,200 | 145,070 | 7·8496 |

From the many experiments on the fracture of iron and steel by torsion, Francis deduced the following values of T; using the above formula for cylindrical bars, and Navier's formula,

$$T = \frac{3\sqrt{2}\,W\,R}{b^3} \qquad [3]$$

for square bars, in which $b$ = the side of the square in inches, and W and R the weight in pounds, producing fracture, and the distance from the axis in inches at which it is applied.

*Experiments by Rennie, given in the 'Philosophical Transactions of the Royal Society' for* 1818.

Bar of English wrought iron, 0·25 in. square .. .. .. T = 65,982
„ Swedish wrought iron, 0·25 in. square .. .. .. T = 61,909
„ shear steel, 0·25 in. square .. .. .. .. .. .. T = 111,191
Average of 3 bars of iron cast horizontally, 0·25 in. square .. T = 64,776

*Experiments given in the Fifth Edition of 'Haswell's Engineers' and Mechanics' Pocket-Book.'*

Bar of Ulster Iron Company's wrought iron, 1 in. diameter .. T = 87,090
„ Swedish wrought iron, 1 in. diameter .. .. .. .. T = 93,965

*Experiments made at the Royal Gun Factories, Woolwich, England, on many Varieties of Cast Iron. Parliamentary Document, July* 30, 1858.

Experiments are given on fifty-one varieties of British cast iron, besides several varieties from other countries. Francis selected the experiments on four varieties of British iron, namely, the strongest, two of medium strength, and the weakest; each result being deduced from a mean of several experiments on bars about 1·8 in. in diameter.

From West Hallam Iron Works, Ilkeston .. .. .. .. .. T = 38,217
„ Netherton Iron Works .. .. .. .. .. .. .. T = 34,490
„ Butterley „ .. .. .. .. .. .. .. T = 33,949
„ Hæmatite Iron Company .. .. .. .. .. .. .. T = 22,132

*Experiments made at the Fort Pitt Foundry, in* 1846, *on bars of different forms and dimensions, of Common Foundry Iron, given in 'Reports of Experiments,' &c., above cited.*

Bar about 1 in. square .. .. .. .. .. .. .. .. .. T = 36,846
„ 1·415 in. square .. .. .. .. .. .. .. .. .. T = 34,443
„ about 1·749 in. square .. .. .. .. .. .. .. .. T = 42,821
„ 1·135 in. in diameter .. .. .. .. .. .. .. .. T = 37,445
„ 1·595 „ „ .. .. .. .. .. .. .. .. T = 42,047
„ 1·955 „ „ .. .. .. .. .. .. .. .. T = 38,851

*Experiments made at the West Point Foundry, in* 1851, *on Greenwood Iron of different grades, mixtures, and fusions, given in 'Reports of Experiments,' above cited.*

Mean deduced from eighteen experiments on bars about 1·9 in. diameter .. .. .. .. .. .. .. .. .. .. T = 44,957

The value of E, for wrought iron, we have previously deduced from English experiments, and tested by a single experiment on a shaft 2 in. in diameter and about 180 in. between bearings. From these experiments we find .. .. .. E = 3,492,539

There being such great irregularities in the values of T, it will not be safe, in practice, to take a mean value, but one near the lowest value.

The values for wrought iron vary from 49,148 to 93,965. For safety, we take for wrought iron .. .. .. .. .. T = 50,000

The values for steel vary from 76,392 to 111,191. For safety, we take for steel .. .. .. .. .. .. .. .. .. T = 80,000

The values for cast iron vary from 22,132 to 64,776. For safety, we take for cast iron .. .. .. .. .. .. .. T = 30,000

We also take for wrought iron .. .. .. .. .. .. .. E = 3,500,000

And for untempered steel .. .. .. .. .. .. .. .. E = 3,800,000

Shafts for transmitting power are subject to two forces, namely, transverse strain and torsion. In shafts of wrought iron or steel, in which the bearings are not very near to each other, a transverse strain, too small to cause fracture, will produce sensible deflection; if this is too great, it will produce sensible irregularities in the motion, and tend towards the rapid destruction of the shaft and its bearings. This limits the distance between the bearings, as the weight of the shaft itself will produce an inadmissible amount of deflection whenever this distance exceeds a certain amount, which varies with the material and diameter of the shaft.

The deflection of a cylindrical shaft from its own weight, supported at each end, but disconnected from other shafts, is given by the formula [4], which is deduced from Navier's formula for the deflection of a cylindrical bar. See 'Journal of the Franklin Institute' for February, 1862.

$$\delta = 0{\cdot}007318 \frac{l^4}{d^2 \mathrm{E}}. \qquad [4]$$

If the several parts are so connected as to be equivalent to one continuous shaft, it will correspond to the case of a beam fixed at both ends, for which case Barlow gives $\delta$ equal to two-thirds of its value in the case of a beam supported at both ends, given by formula [4]. Navier, taking into account the effect of the deflection in the adjacent divisions, finds $\delta$ equal to one-fourth of its value by formula [4]. In order to decide which of these authorities to follow, Francis appealed to experiment.

*Experiment* 1.—A bar of wrought iron purchased as "English refined," 12 ft. 2¾ in. long, 0·367 in. deep, 1·535 in. wide, was supported at four equidistant points, 4 ft. apart. When loaded at the middle points of each division with 52 lbs., the deflection in the middle division was 0·069 in., and the mean deflection in the other two divisions was 0·371 in. The weight on the middle division was then increased until the deflection was alike, namely, 0·281 in. in each division; the weight being 82·84 lbs. in the middle division, and 52·00 lbs. in each of the other divisions. 4 ft. was then cut off of each end of the bar, when the deflection, with 82·84 lbs. on the middle division, was 1·102 in.

*Experiment* 2.—A bar of iron of the same quality and length as in Experiment 1, 0·551 in. square, was laid on the same supports. When loaded at the middle points of each division with 52 lbs., the deflection in the middle division was 0·058 in., and the mean deflection in the other two divisions was 0·314 in. The weight on the middle division was then increased until the deflection was 0·241 in. in each division; the weight being 82·84 lbs. in the middle division, and 52·00 lbs. in each of the other divisions. 4 ft. was then cut off of each end of the bar, when the deflection, with 82·84 lbs. on the middle division, was 0·984 in.

In the case in which the deflections were alike in the three divisions, the middle division corresponds to the case of a continuous shaft supported by numerous equidistant bearings; and the case where the bar was reduced in length, corresponds to that in formula [4]. Comparing the deflections in the two cases in the above experiments, we find by Experiment 1 that the ratio of the deflection of the shaft, simply supported at each end, to that of the continuous shaft, is as 1 to 0·255. In Experiment 2, the corresponding ratio is as 1 to 0·245; the mean of the two experiments giving a ratio of 1 to 0·25, which agrees with Navier, and we must adopt for the deflection of a continuous shaft, from its own weight, the formula

$$\delta = \tfrac{1}{4} \times 0{\cdot}007318 \frac{l^4}{d^2 \mathrm{E}}. \qquad [5]$$

These experiments indicate the effect of connecting the chords of truss-bridges over the piers. Assuming that in a bridge of not less than three equal spans, the top and bottom chords have equal resisting powers, and the whole length of the bridge is uniformly loaded, if the chords are continuous throughout the whole length of the bridge, the deflection of any span, except the end spans, will be one quarter of the amount that it would be if the chords were disconnected at the piers.

The greatest admissible value of $\delta$ in proportion to the length must be determined by experience. Tredgold assumes that, for cast iron, it might be 0·01 in. for each foot in length, or $\frac{1}{200}$ part of the length, *whatever may be the diameter;* but the transverse strain to produce this deflection is a greater fraction of the transverse strain that will produce fracture in a large shaft

than in a small one. The maximum strains of extension and compression in a shaft, for the same deflection, are in proportion to the diameter, while the deflection itself, from the weight of the shaft, is inversely as the square of the diameter; consequently, the deflection, to produce the same maximum strains, must be inversely as the diameter.

Adopting this principle, and the assumption that a shaft of wrought iron or untempered steel 2 in. in diameter may deflect from its own weight 0·01 in. a foot in length between the bearings, we may determine the greatest admissible distances between the bearings of shafts of other diameters, as follows:—

The greatest admissible deflection for any diameter $d$, is

$$\delta = \frac{2\,l}{1200\,d} = 0{\cdot}00167\,\frac{l}{d}. \qquad [6]$$

Substituting this value of $\delta$ in [5] and reducing, we have

$$l = \sqrt[3]{0{\cdot}9128\,d\,E}. \qquad [7]$$

TABLE OF THE GREATEST ADMISSIBLE DISTANCES BETWEEN THE BEARINGS OF CONTINUOUS SHAFTS, SUBJECT TO NO TRANSVERSE STRAIN EXCEPT FROM THEIR OWN WEIGHTS; COMPUTED BY FORMULA [7].

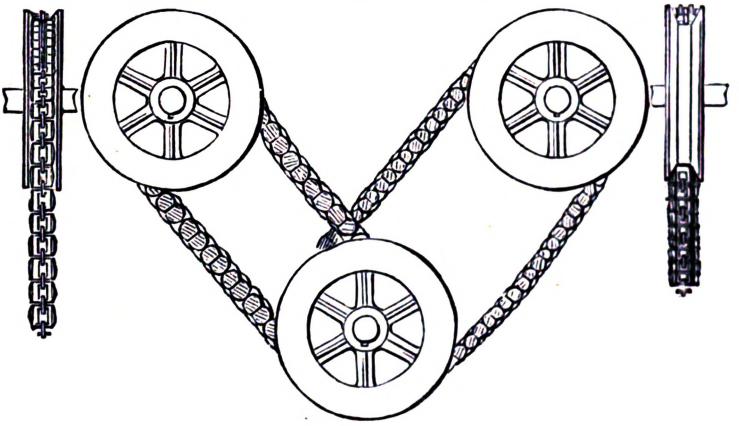
| Diameter of Shaft, in inches. | Distance between Bearings, in feet. | | Diameter of Shaft, in inches. | Distance between Bearings, in feet. | |
|---|---|---|---|---|---|
| | If of Wrought Iron. | If of Steel. | | If of Wrought Iron. | If of Steel. |
| 1 | 12·27 | 12·61 | 7 | 23·48 | 24·13 |
| 2 | 15·46 | 15·89 | 8 | 24·55 | 25·23 |
| 3 | 17·70 | 18·19 | 9 | 25·53 | 26·24 |
| 4 | 19·48 | 20·02 | 10 | 26·44 | 27·18 |
| 5 | 20·99 | 21·57 | 11 | 27·30 | 28·05 |
| 6 | 22·30 | 22·92 | 12 | 28·10 | 28·88 |

In practice, long shafts are scarcely ever entirely free from transverse strains. However, in the parts of long lines which have no pulleys or gears, with the couplings near the bearings, the interval between the bearings may approach the distances given in the table. Near the extremities of a line, the distances between the bearings should be less than those given in the table. The last space should not exceed 60 per cent. of the distance there given, the deflection in that space being much greater than in other parts of the line. In shafts moving with high velocities, it will usually be necessary to shorten the distances between the bearings, as given in the table, in order to obtain sufficient bearing-surface to prevent heating.

**BELTING, CHAIN.** FR., *Ceinture de chaine;* GER., *Kettenseil.*

*Clissold's chain belting*, Figs. 674, 675, 676, 677. This belting is composed of iron links of a peculiar shape, an enlarged cross-section of which is shown in Fig. 677. The links are coupled by

674. 675. 676.



677.

pins, as shown in Figs. 674, 675, 676; each alternate is formed with sockets, in which pieces of hard wood, bevelled at the ends to fit the pulleys, are inserted. It may be observed from the detached section, Fig. 677, that the shape of the groove in the pulleys is such that the belt is clipped between the sides, and a firm hold is obtained. Chain-belts of this kind have now been in use for several years, some of them running at a speed of 1700 ft. a minute; they have been found durable, whilst they work smoothly and without slip.

John Fielden's cast link-chain is shown in Figs. 678, 679. This chain shows that John Fielden has much ingenuity; it is the only faultless cast link-chain which has fallen under our notice.

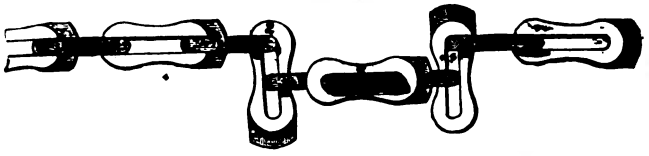
The chain-wheel round which the chain, Figs. 678, 679, may be moved, is given in plan and section, Fig. 682. It has been found that the chain works best when there is a flat web passing from tooth to tooth, as shown in the plan, Fig. 682. Many of these chains, made of malleable cast iron, are successfully used in the woollen-mills of Lancashire and Yorkshire.

678.

679.

The Fielden chain, made of cast brass, is much in use in dye-works. One of the chief peculiarities of this chain is, that it cannot come uncoupled, no matter whether the chain be slack or tight when at work; and yet, a workman once shown how, may uncouple or recouple it in a very short time.

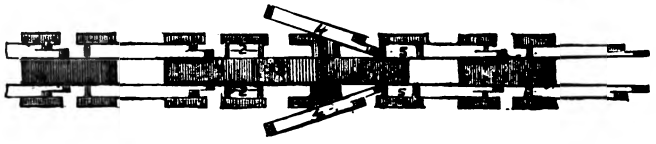
680.



The chain is easily coupled together by commencing at one end, and keeping all the links with lip in one direction when on the plates, as shown in Figs. 678, 679.

For the method of uncoupling, see Figs. 680, 681.

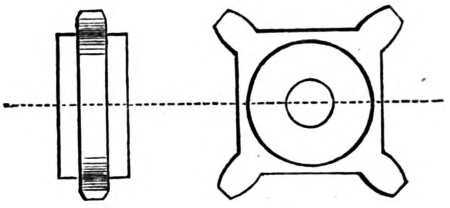
681.



Set the links 2 and the links 5 at right angles to the plates 3 and 6. Place the ends of plates 3 and 6 together, as shown in Fig. 680. It will now be found that the lip of links 4 can be pushed forward into the hollow side of links 5.

The links 4 will then open over the ears of plate 6, so that plate 3 may be removed away. See Fig. 681.

682.



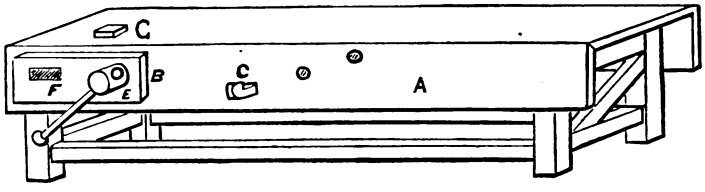
The links 4 may now be put back into their respective places upon plate 6, then turned round and be easily removed from plate 6.

BENCH. Fr., *Établi*; Ger., *Hobelbank*; Ital., *Banco da falegname*; Span., *Banco*.

A bench is a table on which carpenters, joiners, and others prepare their work. It is usually from 10 ft. to 14 ft. long, 2 ft. 3 in. wide, and 2 ft. 8 in. high.

The carpenter's bench is furnished with a screw-board A, Fig. 683, which holds the bench-vice B and the bench-pin C. The vice consists of a cheek, having a screw E working into a nut

683.




fixed at the back of the screw-board, and a guide F. The bench-pin C is made to fit tightly into holes placed at different elevations in the screw-board, its use being to assist the bench-vice in retaining the board whose edges are about to be planed, or, as it is technically termed, *shot*.

On the top of the bench is the bench-stop G, which is a piece of iron made with teeth to catch in the end of the piece of wood to be worked, and prevent it from being pushed forward by the force of the plane.

*Bench-hook.*—A movable pin, passing through a mortice in the top of the bench, for preventing the stuff from sliding while being wrought by the plane.

BENCH-MARKS. Fr., *Repère*; Ger., *Merkzeichen*; Ital., *Punto di paragone*; Span., *Cotas de referencia*.

See Railway Engineering.

**BEND.** Fr., *Tuyau coudé;* Ger., *Knierohr;* Ital., *Gomito.*

A piece of curved pipe connecting two straight portions is designated a *bend.*

Earthenware or stoneware bends are usually double the price of a straight piece of the same length. The price of cast-iron bends is also increased, owing to the pattern being more costly, and, in most cases, having to be specially made.

Wrought-iron pipes can be bent while cold by filling them with lead, and afterwards making it out by heating the pipe.

**BERM.** Fr., *Berme;* Ger., *Berm, Wallabsatz;* Ital., *Banchina;* Span., *Berma.*

See Fortification.

**BETON.** Fr., *Béton;* Ger., *Grundmörtel;* Ital., *Calcestruzzo;* Span., *Hormigon.*

See Concrete.

**BEVEL** or **BEVIL.** Fr., *Angle qui n'est pas droit;* Ger., *Spitzer oder stumpfer Winkel;* Ital., *Smusso;* Span., *Chaflan.*

A bevel in masonry or brickwork is a sloped or canted plane surface.

Any angle except one of 90° is called a *bevel-angle.* See Hand-Tools.

**BINDERS,** or **BINDING-JOISTS.** Fr., *Travon, cheveteau:* Ger., *Unterzug, Mittelbalken,* Span., *Traviesas, tirantes.*

See Joists.

684.

**BIRD'S MOUTH.** Fr., *Joint en biseau, About en Geule;* Ger., *Keilsteg;* Ital., *Commettitura abecco d'uccello;* Span., *Picolete.*

*Bird's Mouth.*—A notch cut at the end of a piece of timber, as Fig. 684.

In bricklaying, a notch cut in a brick to adapt it to any internal angle less than 90° is a bird's mouth.

**BISCUIT MACHINE.** Fr., *Machine à faire le biscuit;* Ger., *Bisquit Maschine;* Ital., *Macchina da biscotti.*

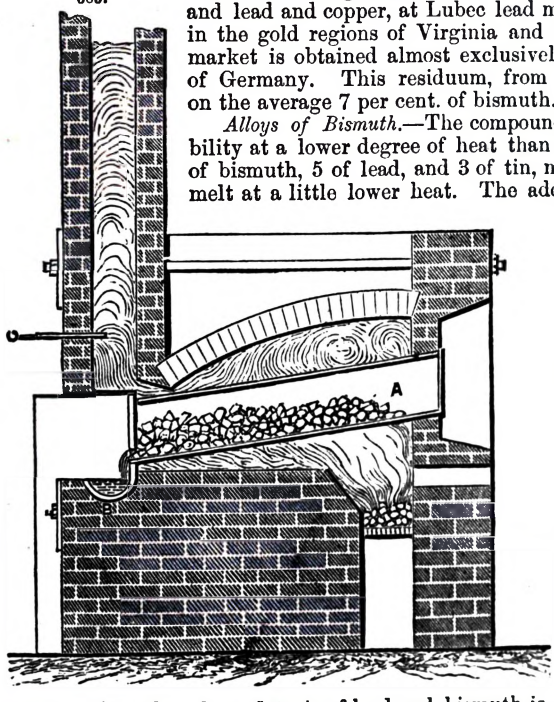
See Bread-making Machinery.

**BISMUTH.** Fr., *Bismuth;* Ger., *Wismuth;* Ital., *Bismuto;* Span., *Bismuto.*

Bismuth is a rare metal, but its distinguished qualities are that it is very fusible, and causes other metals to become fusible also. Like *antimony,* it is very brittle, and of a brilliant lustre; its colour is white, tending to flesh-colour. It melts when pure at 480°; it may be distilled in a close vessel, and then crystallizes in lamina. Water being put = 1, its specific gravity is 9·83, which may be increased to 9·98 by hammering. Bismuth is peculiarly suitable for castings, as it expands in the act of cooling, which renders it peculiarly suitable for castings.

*Ores of Bismuth.*—There are many minerals which contain bismuth, but they do not often occur in such quantities as to make the extraction of the metal profitable. The metal is not very valuable, and, notwithstanding its scarcity, it is sold at a low price. It occurs native, and is then easily obtained. Native bismuth is found in Monroe, Ct., where it is associated with wolfram, galena, blende, and quartz; also in Chesterfield, South Carolina; and, of course, in many localities of other parts of the world. Sulphuret of bismuth occurs at Haddam, Conn. The carbonate is found in the gold district of Chesterfield, South Carolina; and the sulphuret and lead and copper, at Lubec lead mines, in Maine. Telluric bismuth exists in the gold regions of Virginia and North Carolina, U.S. All the metal in market is obtained almost exclusively from cobalt-speise, at the smalt works of Germany. This residuum, from which also nickel is extracted, contains on the average 7 per cent. of bismuth.

685.




*Alloys of Bismuth.*—The compounds of bismuth are distinguished by fusibility at a lower degree of heat than those of most other metals. Eight parts of bismuth, 5 of lead, and 3 of tin, melt at 202°. Two bismuth, 1 lead, 1 tin, melt at a little lower heat. The addition of mercury increases the fusibility of these alloys. One bismuth, 2 tin, 1 lead, is soft solder for pewter. Clichés for stereotypes are composed of 3 lead, 2 tin, 5 bismuth; this alloy melts at 199°. 45·5 bismuth, 28·5 lead, 17 tin, and 9 mercury, is an alloy for plugging teeth; it fuses at 149°. An amalgam of 20 bismuth and 80 mercury is used for silvering the interior of glass globes. Like antimony, bismuth forms an alloy readily with the alkaline metals. Its affinity for arsenic is very weak, like that of phosphorus; both of these substances may be evaporated from the hot metal almost entirely. All its compounds with precious metals are very brittle. Bismuth has been proposed instead of lead for refining silver; but the experiments performed with it were not satisfactory. A compound of tin and bismuth is stronger, harder, and more sonorous than pure tin; and for these reasons it is added to pewter. An alloy of equal parts of lead and bismuth is heavier than the mean density of the two metals, it being 10·709.

*Uses.*—Bismuth is scarcely used alone; it is chiefly employed for imparting fusibility to alloys. Besides the above-mentioned applications, it is used in the alloys of which safety-plates

and plugs in steam-boilers are made. Its oxides are used as cosmetics; also as paints, and printing colours.

*Manufacture.*—The operation of smelting bismuth is extremely simple; the metal having but a weak affinity for other substances is obtained by simply heating its ore. The cut, Fig. 685, shows a modern liquation furnace, by which the metal is obtained. A is a cast-iron retort, at the highest part of which the crude ore is charged; B shows a cast-iron bowl into which the metal flows. About half a hundredweight of broken ore is charged in each retort, of which there are four in a furnace side by side. This quantity nearly half fills a retort, so that the upper part of it is empty. The lower end of it is closed with a clay plate, or slab, provided with an aperture for the discharge of the melted metal. The pipes, when properly ignited, soon cause the metal to flow into the dish B, which contains some charcoal-dust. By applying a brisk fire and some stirring to the ore, all the metal contained in it is obtained within half an hour. The residuum of the ore is now scraped out of the retort into a trough with water, and the pipes are filled afresh. About a ton of ore is smelted in a day of eight hours. The metal is remelted, cast into iron moulds in the form of ingots, and is now ready for the market.

The metal thus obtained is not pure but it may be purified by remelting in a flat earthen, or rather a bone ash-dish, at a low heat, removing the dross as it appears on the surface of the metal. It is advisable to melt the metal thus obtained in a purer form in a blacklead pot, and then cast it into the mould for ingots. Bismuth cannot be freed from silver by these means, in consequence of which the article of commerce always contains some of that metal. The annual production of this metal amounts to nearly 19,000 lbs.

BITS. Fr., *Bittes;* Ger., *Grosse Beting;* Ital., *Bitte.*

See Augers, Braces, and Bits.

BLASTING. Fr., *Pétardement;* Ger., *Sprengen;* Ital., *Minare.*

See Boring and Blasting.

BLAST FURNACE. Fr., *Fourneau à courant d'air forcé;* Ger., *Schachtofen;* Ital., *Forno ad aria forzata.*

Furnaces are classified as *wind* or *air furnaces* when the fire is urged only by the natural draught; as *blast furnaces* when the fire is urged by the injection artificially of a forcible current of air; and as *reverberatory furnaces* when the flame of the fire, in passing to the chimney, is thrown down by a low arched roof upon the materials operated upon.

In general terms, a *furnace* is an enclosed place where a hot fire is maintained, as for melting ores or metals, for warming a house, for baking bread or pottery, or for other useful purposes; as an iron *furnace;* a hot-air *furnace;* a glass *furnace;* an engine *furnace,* and the like. See Furnaces.

The right construction and suitable arrangement of blast furnaces for either hot or cold blast are of considerable importance in the smelting and manufacturing of iron.

Smelting is an operation which is performed in the blast furnace, as it is termed, because of its size and auxiliaries. In it the separation of the metal from the ore depends on the presence of heat, carbon, and the condition that the metal is heavier than the oxidized substances which form the slag. Blast furnaces are used exclusively in America, for smelting fluid iron, and mostly grey iron. In some parts of Europe a lump of solid iron is formed in the hearth of the furnace. But this is an expensive way of smelting iron, and not proper for imitation.

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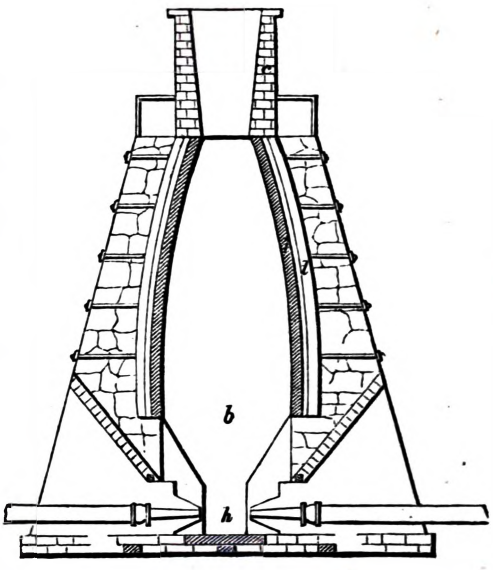


Fig. 686 shows a vertical section of a modern blast furnace. These furnaces are from 25 to 50 ft. high. In almost all instances, the bulk of the mason-work is constructed of rough stones. Sandstone is preferable, but any kind may be used except limestone. The furnace itself forms a pyramidal mass of masonry, commonly as wide at the base as the height from the floor to its mouth. The interior of the furnace is formed of fire-proof material, the lower parts of sandstone, and the upper of fire-brick. The lower part, marked *h*, forms the crucible, or hearth, at which is the strongest heat, and where that part of the ore which has not been smelted in higher parts of the furnace is melted. This part is most commonly square, its sides are from 20 in. to 6 ft. wide, and it is never less than 5 ft., often 8 ft. high. The stones of which they are built in America are exclusively sandstones, while in Europe we find them constructed, not only of this material, but also of granite, gneiss, and even limestones; the latter, however, are becoming rare. Above the hearth *h*, the furnace widens rapidly and forms a gentle slope, *b* the boshes, where the furnace is gradually converted from a square to a round form. At the top, or widest part of the boshes, which varies from 8 to 18 ft. in diameter, the horizontal section of the interior of a furnace is a perfect circle, which is continued up to its mouth. This round part of the furnace is most generally formed of fire-brick, but in some instances of sandstone or shale. It has the form of an inverted cone, in which the sides are more or less curvde. This part of the furnace, marked *i*, is termed the in-wall or lining. All those

parts below the lining are solid stones, and closely joined to the rough walls. The lining itself is not close to the rough wall; there is a space between marked *l*, from 6 to 8 in. wide, filled with broken stones, or broken furnace-slags; these are loose, so as to admit of an independent motion of the in-wall, which is for these reasons made of fire-brick.

Rough stones expand and contract more than fire-brick, and are more liable to fractures; and as injury to the in-wall may cause serious losses, the safest plan is to use good fire-brick for its construction. The bricks are generally moulded in the proper manner for forming a circle, and are from 13 to 18 in. in length, which size decides the thickness of the in-wall. The in-wall rests on the rough wall of the stack, and is in many instances supported by heavy cast-iron beams, which form, in the meantime, the tuyere arches. The mouth of the furnace is, in some instances, very narrow, in others wide; this depends on the size of the furnace, kind of ore, fuel, blast, and management. The diameter of this throat varies from 20 in. to more than 10 ft. In the majority of cases the mouth is provided with a cast-iron cylinder, which forms the throat. This cylinder receives the cold material, and is thus prevented from melting, or from injury. The top of the furnace is generally crowned with a chimney, *c*, as wide, or somewhat wider, than the mouth of the furnace; it is provided with one door at small furnaces, and with several at large furnaces. Through these doors the smelting materials are charged.

At the lower part of the furnace may be seen arches, or recesses in the masonry of the stack. These are formed by dividing the basis of the furnace into four piers, as shown in Fig. 687, and are called side arches, H H, and back-arch, F, and work-arch, G. These recesses are generally covered by semicircular brick arches; in few instances they are formed of cast-iron beams. The arches are from 8 to 16 ft. wide, according to the size of the furnace. At large furnaces, a communication between these arches is effected by a gangway, I I I I, piercing the piers. The front or work arch, often called tymp-arch, shows that the crucible is open here; the discharge of the metal and slag is prevented by the dam-stone K, which is of a triangular section, bedded in fire-clay

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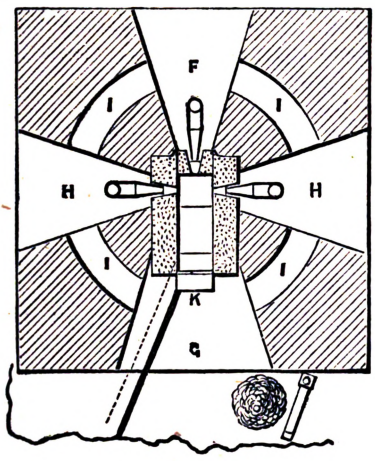


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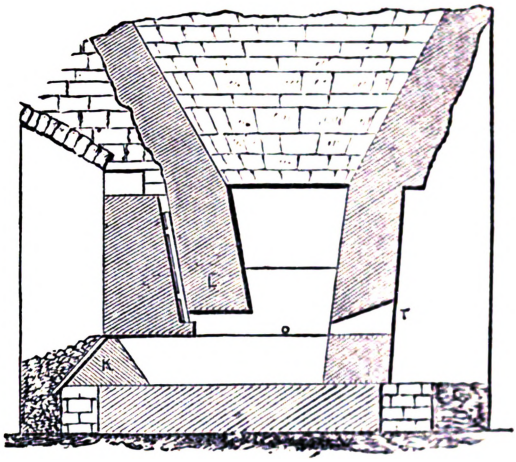


upon the bottom stone. L is the tymp-stone, Fig. 688; it forms, by being raised from 15 to 24 in. above the bottom stone, the aperture for the discharge of the smelted matter, and affords ample space for the removal of any obstructions which may happen to be formed in the hearth. There are some peculiarities in the relative position of dam-stone and tymp, which we shall point out hereafter. The tymp as well as dam-stone are covered with a heavy cast-iron plate, to prevent their being injured by charging heat. From the top of the dam a gentle slope is formed for the discharge of slag which floats continually from the furnace. At the base of the dam-stone a small aperture—the tap-hole—is formed by cutting a part off from this stone before it is bedded.

In Fig. 688 an enlarged view of the hearth and boshes is represented, which presents all their parts more distinctly. It shows the principal joints of the hearthstones, and the manner in which the boshes are formed. These are, in small furnaces, constructed of a mixture of clay and sand, and in large charcoal, anthracite, and coke furnaces, either of fire-brick or of sandstones.

In the plan here represented the furnace is provided with three tuyeres, T. The blast pipes are conducted from the blast machine under the bottom stone of the hearth, and branches from it are led to the tuyeres. Small charcoal furnaces, which smelt from 20 to 25 tons of metal a week, work by one tuyere from one of the side arches. Large charcoal furnaces are worked by two tuyeres on the opposite sides; while anthracite or coke furnaces generally have three, and some five or six tuyeres. Conducting the blast pipes under ground, it has advantages in respect to saving room, but it causes vexation in case any accidents happen to them, which often occur by using hot blast. It affords, however, in the meantime, the security of a dry bottom stone, which is of great value at any furnace. If the blast pipes are thus conducted under the hearth, they should be placed in a spacious channel, so that necessary repairs may be effected at any time. The bottom stone is laid upon a strong cast-iron plate which covers this channel.

The rough walls of a furnace may be erected with little lime mortar in the joints; in fact, roughly-laid stones appear to form the best stacks. When the masonry is well joined, and filled close with mortar, a system of air-channels is required to facilitate the escape of moisture which

adheres tenaciously to any masonry. In all instances, a stack may be erected of hewn stones, bricks, or ore, roughly put together; but a well-arranged system of iron binders is required to prevent a separation of the mason-work in consequence of the ever-active expansion and contraction of the building materials. The mode of affixing these iron binders, or ties, is indicated in the various drawings; and more particularly in Fig. 689, which presents a horizontal section through the widest part of the boshes. The particulars respecting the arrangement of these ties are subject to the discretion of the builder; but we may remark that there never can be too many binders in a stack. A large number of light bars is preferable to a small number of heavy ones. These binders are wrought iron, generally square bars from 1½ to 2 in., provided with keys at both ends, in preference to screws and nuts, which are not often used. Each end of a binder is also provided with a large cast-iron washer, which covers the channel as well as the stones nearest to the binder. As we have said, the form of these binders is generally that of a square bar; but a flat form of bars is preferable. These binders are located in spacious channels, so that they may be taken out and mended in case any of them break.

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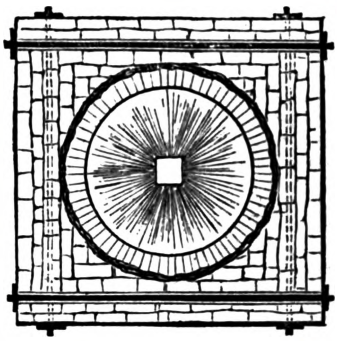
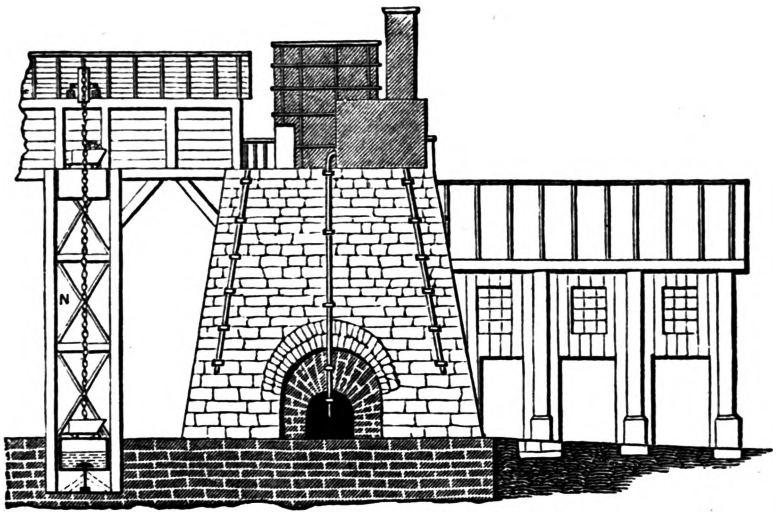


The furnace represented, Fig. 686, is located near the side of a steep hill. The hill and furnace are then connected by a bridge, constructed of wood, or in some instances of stones, or bricks. Upon this bridge a light building, the bridge-house, is erected, which serves as a store-house for fuel, ore, and flux, sufficient to feed the furnace for one or two days. Dry stock is thus protected against rain or snow. At large furnaces, no such use is made of the bridge-house, because it would require to be of too large dimensions. When a furnace is erected on a level place, or when no advantages can be obtained by locating the stack near a hill, which is decided by the mode of supplying the ore and coal, these materials are hoisted by machinery into a tower. Wheel-barrows, which contain the smelting materials, are pushed upon platforms and are raised by chains to the top of the furnace. In Fig. 690 such an arrangement is represented. The tower N is

690.




generally erected of strong timbers, and its top connected with that of the furnace by means of a wooden bridge. A platform is made, which forms in the meantime a cassoon, for the reception of so much water as will balance the load of ore, or coal. Two such platforms are suspended on a strong chain, over a rope-barrel, and when the lower platform is loaded, a current of water is conducted by means of leather hose, into the box, or cassoon, which forms the upper platform. When the amount of water, which flows from a reservoir placed at the top, together with the empty barrows, is heavier than the loaded platform below, the water is shut off, and the loaded platform ascends, while the empty one descends. When the cassoon with water arrives beneath, the upper platform is locked, and the water below is discharged by a self-acting valve, into a drain below the level of the floor. The rope-barrel is provided with a strong brake by which to arrest the machinery, in case an accident happens to any part of it.

This machinery for hoisting is convenient, inasmuch as the power to set it in motion is easily applied, and always at the command of the workmen, provided the cistern is always supplied with water. At the furnace here represented the hot-blast apparatus is placed at the top. The cold blast is conducted upward, and the hot air down to the tuyere. Under this arrangement considerable pressure in the blast is lost, which may be in some measure modified by employing wide pipes. At most furnaces which have been recently erected, both hot-blast apparatus and steam-boilers, which supply the blast-engine with steam, are located on the top of the furnace. For these reasons the area at the top is enlarged. The furnaces are thus made more massive, consepuently

there is less loss of heat by radiation from the furnace, and room for a large mouth. The hot-blast apparatus is, in these instances, located behind the steam-boilers; it receives the waste heat when it has passed the boilers. In some instances the top flame is divided, and partly led under the boilers and partly into the hot-air stove.

Whatever may be the dimensions of a furnace, or whatever kind of fuel or ore is used, the work is more or less modified by local circumstances. When a furnace is newly built, or has been out of blast, or has a new hearth put in, a slight fire is at first kindled at the bottom while the dam-stone is wanting. In order to protect the hearthstone against the immediate contact of a strong heat, it is lined with common bricks, which prevents the flying of these stones. The aperture formed by the tymp, bottom stone, and side stones, is walled up by common brick, and only a few small apertures admit of air for combustion. The hearth and stack are thus slowly dried, which may require from three to ten days. When the hearth has been for some days thoroughly warm, the brick lining is removed, and it is filled to the top of the boshes with either charcoal, anthracite, or coke, whichever may be the combustible used for smelting. The tymp is open, in case the hearth is warm and dry; but when any doubt exists as to its being dry, ashes or sand is thrown on the coal in the tymp to prevent a rapid fire. In order to remove clinkers which may be formed in the hearth, it is cleaned every twelve or twenty-four hours; and when the heat is strong, or an early starting of the furnace is contemplated, a grate is formed by means of ringers—long iron bars—as shown in Fig. 691. Thus a strong draught is produced, a rapid combustion ensues, and the heat is augmented. If these bars are withdrawn after fifteen minutes or half an hour's time, the hot coal, descending on the clean hearth-stones, will heat them thoroughly, and prepare them as well as the bottom stone for the reception of hot metal. One day, sometimes two or three days' heat, which time may be shortened by the repeated formation of grates, will prepare the hearth; the fuel has been, all this time, held as high as the boshes.

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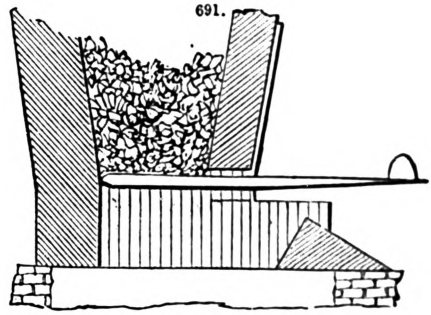

When thus far heated the furnace may be charged with ore. In small charcoal furnaces the coal is generally filled higher than the boshes; but in large ones, and those which are thoroughly heated, there is no need of having much fuel. The furnace is now regularly charged alternately with ore and coal; the ore amounts to only half of a full charge, but the measure of coal is always the same. These charges are not made in rapid succession, but the flame is allowed to become visible on the top of the last charge before another is filled. The furnace is thus slowly fed by alternate charges of ore and coal; and, in order to facilitate the ascent of the gases, coarse coal is selected; or, when charcoal is used, brands or wood are mixed with the coal. When full to the very top, the furnace is ready to receive blast, and not sooner. Some founders usually let on blast before a furnace is quite full. This is imprudent; it causes disorder from the start. When the furnace is thus filled, the ore is drawn down by repeated gratings, which are so managed that the bottom is properly heated. When the first signs of slag or iron appear at the tymp or the tuyeres, the bottom is once more cleared of all adhering cinder, the dam-stone put in its place, and the dam-plate bedded in clay upon it. A large coal or coke, or, what is better still, a mixture of fine damp coal and a little clay, is filled into the tap-hole; a stopper, or at first only heavy dust, is filled under the tymp, and the blast put on. At the first, only weak blast is used; in fact, for the next two or three weeks the furnace does not receive full blast, in order not to injure the new hearth and in-walls by a too sudden and strong heat. A furnace is stouter with about half the pressure which it will take, and that gradually increased in the course of some weeks. A few hours' blast will raise the fluid cinder to the top of the dam-stone; the blast may now be stopped for a few minutes, the hearth tried by a light bar as to cleanliness, and if found free from clinkers or cold slag, a light stopper is formed of clay and coal-dust, the tymp shut, and the blast let in again. The melted iron accumulates now at the bottom of the hearth, and the slag runs over the dam-plate and is carried away. The furnace, of course, is perpetually filled with coal and ore, so that the materials are always level with the top. It must be a standard rule never to blow a furnace by low stock, no matter how it works: it must be full. In cases of imminent danger of chilling, a sinking of charges is excusable, but only to be refilled by dead charges; that is, coal without ore.

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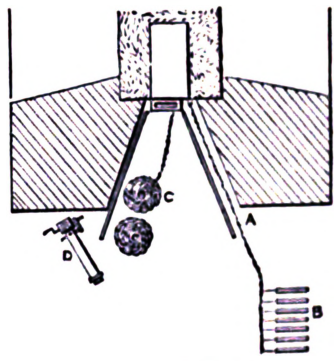


It will require, according to the kind of furnace, from twelve to twenty-four hours to fill the hearth with iron. If possible, the iron ought to come near the top of the dam, before the tap-hole is opened for the first time. The tap-hole is generally at the right-hand side in the tymp-arch, near A, Fig. 692. A channel,—run,—dug in moulding sand, conducts the iron to the pig-bed, B, where the pigs are previously moulded into sand or coal-dust, or dust of anthracite or coke, by means of wooden patterns. Running the iron into iron chills is not much practised. It is confined to only a few furnaces near Baltimore. If the iron is tapped before the pool is quite full, the hearthstones below the tuyeres are liable to be coated with a dry, tenacious cinder, which may cause serious vexation. Such dry cinders cause cold, white iron, and may

occasion the freezing of the iron in the bottom. When the iron is thus tapped from the furnace, the blast is slaked, or stopped, the clinkers and cold cinder removed, and a fresh stopper of clay and sand placed under the tymp, and the blast put on again.

The first iron made should always be grey iron; for these reasons the ore charges are light. An increase of ore must be made gradually and very slowly, proceeding with the greatest caution as to the increase of burden. White or mottled iron, in the first week of a blast, is an indication of scaffolding the furnace. The fluid cinder thus formed is liable to adhere to the in-walls and cause troublesome concretions. When grey iron is smelted the cinder is not very fluid, and may descend into the crucible before it becomes sticky, where the heat is strong enough to remove it at any time.

The tymp-arch is divided into two parts, as shown in Fig. 692. The run for the fluid iron is as much lower than the part C in the middle as the height of the dam-stone. C forms somewhat of a slope, falling from the dam-stone gently. At the left-hand side are two cavities, into which the cinder runs alternately. About a ton of it is necessary to fill such a cavity with slag. A piece of pig iron, or any other iron, is set vertically into the centre of the empty cavity, the cinder flows around it, by which it is firmly held, and, when the mass is nearly cold, it may be lifted by means of a crane located at D. It is deposited on a horse-cart, and carried away. The slope C is separated from the run A, and from the slag-trough, by cast-iron plates, set so close to both sides as to afford only sufficient room for either the iron or the slag to be removed. The room, or slope, thus formed, is necessary for the furnace-men to stand upon and work the furnace. In order to make this space as large as possible, the tymp-arch is considerably larger than the tuyere-arch.

Having thus far given a general description of a blast furnace, its construction and mode of operation, we will now take notice of some of its most important particulars. To commence with the bottom stone. This part of the furnace should be particularly dry, and, if convenient, even warm A cold or damp bottom causes white iron and waste of fuel. In some parts, particularly in Sweden, the bottom is purposely kept cool; but not so in this country. It happens at some old furnaces that the foundation is not perfectly dry, for want of drains; but furnaces recently erected are well provided with means for the removal of moisture. Some kinds of ore, but chiefly the quality of iron smelted, afford the reasons for having a cold bottom stone; considering, however, the greater use of fuel incident to it, the advantages are in favour of a dry and warm bottom. The leading form should be the one represented in Fig. 693, for the foundation of a furnace. A spacious archway crosses under the furnace between the pillars, so that a man may enter and examine it. Any moisture which happens to penetrate from above, which is often the case at hot-blast furnaces, thus subsides quickly, and cannot do much harm. In the meantime, it affords an opportunity of correcting the discharge of water, in case there is any obstruction. A damp bottom stone is not only the cause of waste of fuel, but it produces vexatious concretions of cinder below and around the tuyere, which cause much trouble to the founder. The bottom stone should be in one piece, if possible, but there is not much harm done if it is spliced, provided the joint is close, and the stone safely bedded. It should be a hard, well-dried sandstone, with a uniform grain.

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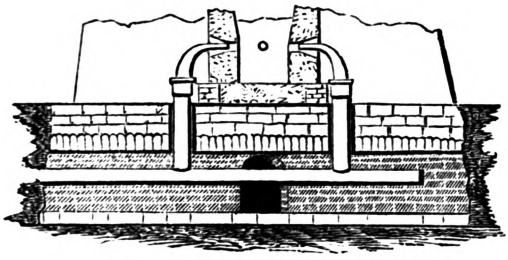

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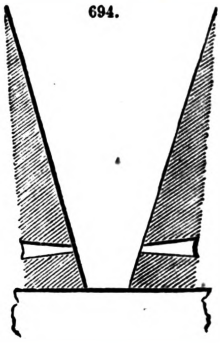

The plan of the hearth is a square, and seldom round or elliptic; the dimensions of the hearth depend entirely on circumstances. A furnace in western New York—Siscoe furnace—which melts a mixture of magnetic ore and hematites, principally the former, is 2 ft. 10 in. wide, 18 in. high below the tuyere, and 20 in. above the tuyere, where the boshes commence. Such a low hearth is suitable for magnetic ore, spathic ore, and some specular ores, but it would not work well with hematites; for the latter kind of ore requires a higher hearth above the tuyere. The charcoal furnaces of Pennsylvania, U.S., are not often less than 4 ft. high above the tuyere. Ores which melt easily, or which are porous and form grey iron, ought to be smelted in a high hearth. The height of a hearth is regulated by the ore, but the size of it at the tuyere is determined by the fuel. A hearth for anthracite or coke is not higher than a charcoal hearth. For ores which melt with difficulty, a low hearth—in fact, one where the boshes commence at the tuyere, as shown in Fig. 694, is considered profitable, and for porous hematites it may reach 1·5 ft. above the tuyere. The space below the tuyere is generally plumb; above it, the batter is from $\frac{1}{24}$ to $\frac{1}{6}$; that is, one half-inch to the foot for very mild ores, and 2 in. to the foot for refractory ones. A high crucible has always more taper than a low one; and one for rich or refractory ores more than one for impure and fusible ores. When forge-pig is smelted, the hearth is lower or more tapered than for grey or foundry pig. The hearth should be wider, and have more batter, when much than when only a little iron is to be smelted. The height and batter of a hearth are in fact not of so much importance

as is commonly supposed. It is expensive to smelt grey iron in a low or much-tapered hearth, and it is expensive to manufacture forge-pig in a high hearth. A high hearth always causes inferior forge-iron. The high crucible saves fuel and ore, but works slow If we assume that a furnace without a hearth, where the tuyere is only 8 or 10 in. above the bottom, and the batter of the boshes drawn down to the tuyere, as shown in Fig. 694, and also that a furnace of this construction produces the best forge-iron—then regarding this as one extreme of the forms of a hearth, and considering the other extreme to be a hearth 6 ft. high, and only ½-in. batter to the foot, and assign to this the capacity of producing the best foundry-pig iron—we shall have the intermediate forms nearly in the following order for ores. Starting with no hearth, or the lowest hearth, low pressure in blast, forge-pig, and much iron, the ores which may be smelted to advantage are as follows: raw sparry carbonates, raw magnetic ore, silicates and forge-cinder, raw argillaceous ore, crystallized peroxide, specular ore, compact peroxide, red oxides, roasted carbonates, roasted magnetic ore, roasted argillaceous ore, raw hematites, roasted hematites, pure bog ores, and bog ores which contain much phosphate. The series of ore inverted will work in a high hearth, strong blast, foundry-pig, and smelt slowly. Bog ore may be smelted in a low hearth, but not to advantage. As the ores are generally impure, a great deal of iron is lost in the slags, and consequently much coal is used; the yield is bad, and however good the iron may be in the forge, it is of no use in the foundry. If, on the contrary, we smelt refractory ore, commencing with the series, in a high hearth, the yield is poor, much coal is used, the iron never good for the forge, and not useful in the foundry. We thus see how much the form of a hearth is dependent upon a variety of circumstances, which must be considered in its construction. If we erect a cylindrical high hearth for smelting magnetic ore, and intend to smelt good forge-pig, and much of it, we certainly fail in the attempt. And if we desire to produce foundry-pig, of bog ores, in a furnace without a hearth, we shall find the iron very poor, weak, and hard, consuming much coal and ore in its manufacture, and not suitable at all to be worked in the forge. By considering these facts, we distinguish easily the correct form of hearth for certain kinds of ore, as well as quality and yield of iron.

One side of a horizontal section of the hearth, or the distance between the tuyeres, is never less than 18 in., and not larger than 8 ft. Round or oval sections of crucibles are not often used, and we shall not allude to them. The true measure of a hearth is the contents of the area, for which we assume one side of a square. These dimensions are somewhat controlled by the nature of the ore, but depend chiefly on the quality and kind of fuel, on the quantity and kind of iron to be smelted, on the pressure of the blast, and on the number of tuyeres. A hearth of only 18 in. square at the tuyere, which is worked by one tuyere, will make very little iron—2 or 2½ tons in twenty-four hours. These dimensions are only suitable for working by weak blast, with ½-lb. pressure, and charcoal. In fact, all dimensions below 30 in. are for charcoal only. A hearth of 24 inches may produce from 3 to 5 tons per diem, with ¾-lb. blast and one tuyere; two tuyeres may bring the yield to 6 tons a day. A hearth of 30 in. may be worked by three tuyeres, ¾ to 1 lb. pressure, and produce from 6 to 10 tons of metal in twenty-four hours. The ore has much influence on the yield. A hearth of at least 30 in., and from that to 4 ft. in width, is used for smelting by coke, the yield of the furnace being in ratio to the size and amount of blast; it varies from 10 tons per diem to 16 or 17 tons. We find in anthracite furnaces—the largest hearths in them—the distance between the opposite tuyeres is not less than 40 in., and sometimes it is as wide as 6 ft. An old hearth is frequently found to work well with a width of 8 ft. The yield in these furnaces varies from 10 tons per diem to 30 tons, according to size, ore, pressure of blast, and number of tuyeres. Large-sized hearths are generally of a round form.

*Pressure of Blast.*—The density of blast depends strictly on the quality of fuel. It has been observed that soft charcoal works best with ½ to ⅝ lb. pressure to the sq. in.; hard charcoal, with ⅝ to 1 lb. pressure. The best wood charcoal will not bear more than this density. Raw bituminous coal, or coke, is worked to advantage with 2½ lbs. to 4 lbs. pressure, and anthracite should have at least 4 lbs. We have no evidence that more density is injurious to the operation with anthracite. When less pressure than this is at our disposal, either from want of power or an imperfect blast-machine, the width of the hearth should be reduced, to produce the necessary force of current in the fuel. When hot blast is used, the densities are as above stated; but with cold blast they may be considerably increased. As the effects of hot blast may be in some measure produced by higher densities, the best results must, as a matter of course, be obtained when pressure and temperature are so regulated as to work the ore with the smallest amount of fuel. We are not informed what density of cold blast anthracite coal will bear; but we know that strong coke will bear 6 lbs., hard charcoal 1 to 1½ lb., and soft charcoal to ¾ and 1 lb.

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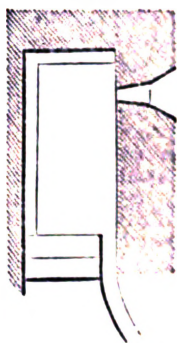

*Number of Tuyeres.*—The number and size of tuyeres depend on the size of hearth, the quantity of iron to be made, and whether hot or cold blast is used. In a small furnace, where charcoal is used, and the production is limited, but one tuyere is used; and this is applied at one side of the hearth, as shown in Fig. 695, and at the side of the tap-hole. It is a remarkable fact, that all attempts have proved futile to work a furnace by placing the tuyere in the back stone, opposite the *tymp.* This appears to be its natural position, but in practice it does not prove so. Good coal, fusible ore, strong blast, and a well-sized hearth, will produce a large quantity of iron with one tuyere. Some furnaces smelt as much as 7 tons per diem by these means. There are great advantages in working one tuyere, particularly with refractory ores and cold blast. All clayish and siliceous ores work better with a single one. When a second tuyere is used, it is placed opposite the one shown above. At charcoal furnaces we do not often find a third tuyere. At coke and anthracite furnaces we find at least two tuyeres, and in most cases three; and sometimes as many as five or six. Then the section of the hearth is round, and the tuyeres are placed

as shown in Fig. 696. This arrangement is well adapted to work by hot blast, but troublesome in using cold blast, on account of the cooling influence of the many apertures. Blast, strongly heated so as to prevent chills at the tuyeres, works admirably well by such an arrangement. A wide hearth and hot blast will admit of the use of more tuyeres than a narrow hearth and cold blast.

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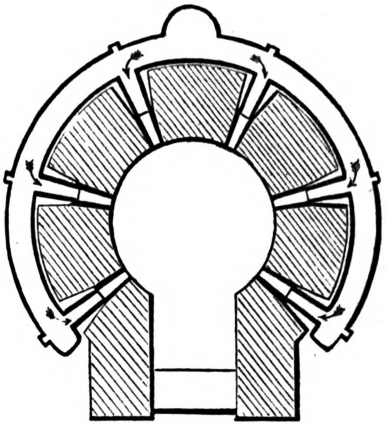

*Size of Boshes.*—That part of the furnace commencing at the top of the crucible, which forms a slope more or less steep, the form of which varies very much, will be easily understood after the preceding remarks. The width of boshes, which means the largest diameter of the interior furnace, depends in some measure on the fuel, but chiefly on the quantity of blast which is brought to bear upon the fuel. The diameter, or rather the slope of the boshes, depends also on the kind of ore which is smelted. We may reasonably assume that this slope is intended to perform a certain service, and that can be no other than gradually to diminish the force of the current of blast. As has been demonstrated in previous pages, the current of blast carries along with it particles of carbon, which may be either dissolved in the gases or not. They will be deposited where the current or temperature is too weak to hold them longer in suspension. This fine carbon is absorbed by the porous ore. The size of the boshes must be, therefore, in ratio to the quantity of blast and the kind of fuel; assuming that both current and temperature are at the greatest diameter, so far diminished as to deposit the particles of carbon. If the boshes are too narrow for a certain quantity of blast, the point of depositing carbon is carried higher and the smelting of the ore commences where it is liable to deposit refractory slag on the slope, causing scaffolding. If the diameter is too large, the ores are carbonized too low, and the slightest alteration of heat must inevitably deposit partially melted ore in the widest part of the boshes, causing concretions. In cases of doubt, it is preferable to have the boshes too narrow, rather than too wide; but we must be aware that nothing has more influence upon the quantity of metal smelted than the dimension of the boshes. But if the furnace cannot be supplied with sufficient blast, it is very vexatious to have the boshes too wide. The extreme diameters in use are from 7 to 18 ft. Charcoal furnaces will bear 9½, and in some instances 10 ft. of width; but the latter is rather a large size. Coke furnaces are not often less than 12 ft., and do not work well if larger than 15 ft. Anthracite appears to afford a wide range; we find furnaces of 10 ft. boshes, and also of 18 ft., or nearly four times larger. As the quantity of blast is in proportion to the fuel, and that in some measure controlled by the quantity of metal made, we find that the production of a furnace is nearly in proportion to the size of the boshes; still, this rule is not so perfect as to admit of correct deductions. The kind of ore and quality of iron smelted exert almost as much effect on the yield of a furnace as the size of boshes. Fusible, well-fluxed ore furnishes more iron, and a larger quantity of forge than of foundry iron may be made in the same time by boshes of the same size. When the diameter depends on the quantity of blast, the slope of the boshes is regulated by the ore and the quality of iron smelted. A slope of 50° is commonly adopted in small furnaces where fusible bog ores are smelted; even 45° are not considered too flat. Raw ores, of the primitive formation, are smelted in slopes of from 70° to 75°, as shown in Fig. 694. Between these two extremes we observe many varieties of slopes. Close, compact ores, which do not form grey iron, are smelted in steep boshes; and ores which are inclined to produce a grey fusible iron may be smelted in flat ones. Foundry iron is better when made in flat boshes, and forge when made in steep ones. The yield of a furnace is greater in the latter than in the former. The use of fuel is also greater in steep than in flat boshes. This depends, however, so much on the form and composition of the ore, that in these respects little influence is exerted by the slope of boshes.

That part of the furnace commencing at the widest part of the boshes and extending to the top is always of a conical form, with straight, or more or less curved sides. By examining the use of this part of the furnace, we arrive at its correct form. In practice, we find it such as is represented in Fig. 697. We shall not consider the advantages or disadvantages of these forms of in-walls, but proceed to define the use of this part of the furnace. Assuming that the operation of reviving and melting the metal and the slag is carried on in the lower part of the furnace, from the largest diameter downwards—which is not always true, as we shall see hereafter—we discern the use of the space enclosed by the in-wall. Nothing is performed in it except the evaporation of water, and of gases from the ore and coal. In reducing the ore, these substances should not be present. Water, as well as hydrogen, free oxygen, or nitrogen, are of no use in the crucible; the first and the second are actually hurtful. The object of this space, therefore, is to evaporate water from ore and coal without causing injury to the form of these substances. A high heat, of course, will evaporate water sooner than a low one; and it will also break coal and some kinds of ore, and form dust of them. For these reasons, a high heat at the mouth of the furnace is often found to be injurious to the smelting operation. Charcoal requires at least twenty-four hours to dry it at a low

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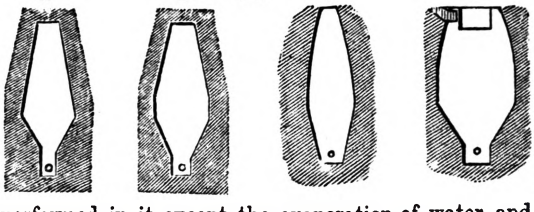

heat, and some kinds of clay or argillaceous ore three times that length of time. When coal and ore may be dried in twenty-four hours, without injury to form, the size is sufficient when the capacity of the furnace above the boshes is sufficiently large to hold ore enough to work for twenty-four hours. When 10 tons of iron are smelted in that time, and 3 tons of ore and 200 bushels of coal are required for 1 ton of iron, the furnace must hold 30 tons of ore and 2000 bushels of coal above the boshes. Generally we find the capacity somewhat greater; but there is no necessity to have more stock in the furnace, whether charcoal or anthracite. Where coke or raw bituminous coal is used, the case is different. This fuel contains always more or less hydrogen, the pressure of which is highly injurious in that part of the furnace where the iron is received. It requires a red heat and a liberal supply of air to expel hydrogen from a large body of coal, and also much time. In this case little can be done in twenty-four hours, and therefore such furnaces have a capacity for three days' stock. The form of the in-wall, if curved or straight, cannot therefore have much influence on the operation; but a gentle curve, or a cylindrical part above the boshes, is found advantageous. This will afford some play for the oscillations of blast, and prevent scaffolding on the slope of the boshes. The curved form shown in C, D, Fig. 697, affords one advantage—namely, the same capacity with less height; and for this reason the curve is advantageous. It has been observed, that beyond a certain limit there is no advantage in increasing the height of a furnace. This may be 40 ft. for charcoal and anthracite, and 50 ft. for coke or bituminous coal. A lower furnace works easier, makes better iron for the forge, and, when well arranged—that is, of sufficient capacity—does not consume more coal in proportion to the iron smelted than a high furnace. It is, therefore, desirable to operate with the least height. This can be accomplished only by curving the lining so as to gain in the capacity. If this space of the furnace serves no other purpose, we may give any form we choose, without injury to the work. It has been proved by experience that the curved lining and a low furnace work better than a straight lining and high stack. The curvature is, of course, never to extend beyond the largest diameter of the boshes.

*Size of Mouth.*—On this subject a great deal of controversy has arisen without any satisfactory result. It is settled that narrow tops and too wide mouths cause a waste of fuel.

If we consider the object of this aperture we shall be able to determine its size. The mouth is chiefly for charging the furnace with ore, coal, and flux, and for the escape of the waste gases. If the current of the gas is too strong at the top, a large quantity of small particles of carbon are torn loose and escape, thus causing a loss of fuel. If the throat is too narrow, the ore is apt to bake and form lumps, which pass into the centre of the furnace, and descend to the hearth unsmelted. A mouth of the proper size will cause some ore to move towards the in-walls, while the large mass will remain in the centre. When the throat is narrow, a marked difference is found in the operation of the hearth when a fresh charge is thrown in and when it is down. This is particularly the case at small, low charcoal furnaces. The oscillation in heat thus produced causes a waste of fuel. A narrow throat will work hotter than a wide one, and thus cause the flying of coal and ore, which makes dust in the boshes and forms an obstruction to blast. There would be no objection to making the mouth as wide as the boshes, were it not that by so doing the ore is thrown chiefly near the in-walls, which in melting will cause scaffolding; and if in this case the ore is charged in the centre of the furnace, the waste heat escapes chiefly at the in-walls, preventing it from becoming sufficiently dry before arriving at the hearth. These reflections lead to the conclusion that half the diameter of the boshes should be nearly the diameter of the mouth, which is confirmed by practice. At charcoal furnaces the diameter of the mouth is generally made narrower, under an apprehension that heat will be lost. At coke and anthracite furnaces, we find the throat wider than half the diameter of the boshes; it ranges between $\frac{1}{2}$ and $\frac{3}{4}$ of it. There is less danger of losing heat by a wide than a narrow mouth; the latter always consumes more fuel than the former, but it requires more attention on the part of the founder, because of its tendency to cause scaffolding. The mouth may be formed of an iron cylinder or a brick wall.

The mouth is sometimes surmounted by a chimney; this is required to protect the workmen against injury from the flame. An open mouth causes improper filling, because the men sometimes cannot get near the proper place, in consequence of the flame which is driven there by the draught or wind. It is in all instances proper to erect some protection for the fillers. A brick chimney, well provided with binders, and some apertures for charging, is all-sufficient for the purpose.

Blast furnaces have in most cases, and should have in all cases, a roof over the top of the stack, a bridge-house, and a moulding-house. The uses of these buildings are obvious—for the

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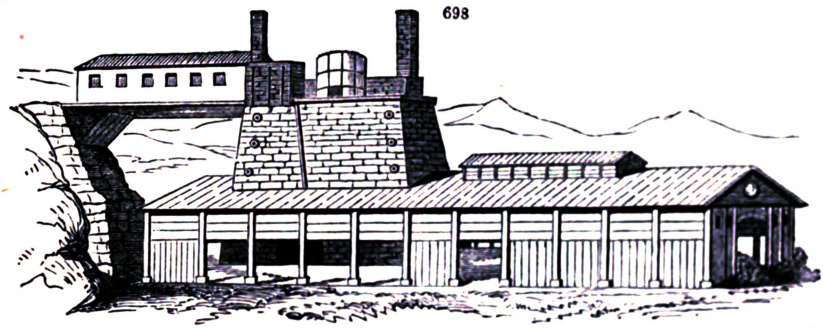

protection of those who work the sand in the pig-bed, and the ore, coal, and furnace, from the effects of rain and snow. The whole of a blast furnace, including all these buildings, assumes then a form such as is represented, Fig. 698. All these buildings should be constructed of iron, or coated

with a fire-proof paint; for any losses in consequence of a conflagration in these establishments are of a serious nature, because they cannot well be covered by insurance.

We recognize two distinct and active principles in smelting iron ore, or, in fact, any other ore. The one relates to those instances where porous ore is smelted; the other is that in which compact ores are reduced. In former pages we had occasion to allude to this subject, and remarked that carbon must be dissolved in the gases of the lower part of the furnace, or we could not account for grey iron. The carbon may be dissolved in hydrogen, or any other gas; it will be attracted by the oxygen of the ore, the pores of which it will fill if it is porous. By whatever means the carbon is dissolved, or set in motion, the effect must be in all cases the same. If ore is very porous, it will absorb much carbon, and form a black or brownish-black mass, which is more refractory than pure ore, and which melts only in the high heat of the crucible. This condition of the ore in the furnace has been proved by actual experiments. In drawing out the contents of a furnace, when in the best condition for smelting, the ore was found to be in this state. Under these circumstances, iron is smelted with the smallest amount of fuel, grey iron follows with the greatest facility, and good quality can be depended on. This mode of smelting can be practised only on porous ores, bog ores, hematites, soft red oxides, and roasted ores. It requires a large space above the boshes in order to saturate the ore with carbon, and flat boshes to concentrate the heat below them and in the centre of the furnace; it also requires a highly-charred fuel, which is free from hydrogen. It has been observed that, when it is desirable to smelt grey iron, raw fuel or imperfectly-charred fuel does not facilitate the operation. On the contrary, raw fuel leads to the formation of white iron. Grey iron, of course, is smelted by raw bituminous coal, and also by wood; but we speak here only of ordinary circumstances, in which the fact is as we state. If the medium in which the carbon is dissolved is indifferent in respect to the formation of grey iron, carburetted hydrogen ought to be particularly suitable for the formation of it. But this is not the case. Fuel which contains hydrogen forms, at best, an impure iron; and if grey, it contains but little carbon. Carburetted hydrogen certainly deposits more carbon in the ore than can by any other means be accomplished; but hydrogen reduces many substances, such as silex or lime, which are not reduced by carbon except under peculiar circumstances. When hydrogen penetrates oxide of iron at a low temperature, it forms a powder of metallic iron, which does not so readily combine with carbon as a powder of oxide of iron exposed to the same degree of heat. We discern thus very readily the means by which grey cast iron, of good quality, can be formed.

In these remarks we have alluded to one extreme—that is, the formation of grey iron from porous ore; we shall now examine the other, or the formation of white iron from compact ore. The best material to serve as an illustration is a silicate of iron. When forge-cinder is charged to a blast furnace, it cannot absorb carbon in its pores: for it is compact, and not accessible to any gas, so far as its interior is concerned. This substance will move unaltered in the furnace, to a point where the heat is strong enough to melt it. Here it is converted into a fluid cinder, or slag, and trickles down through the hot coals; these absorb oxygen from iron and other metals, and if the height of the column of hot coals is sufficient, all the iron may be reduced before the fluid slag arrives at the tuyeres. No carbon can be absorbed by the iron in this case: for it forms large globules, and is not in a condition, or not in so close contact with the metal as to combine with it. The fluidity of the metal is in this case most generally produced by substances which are nearest to the iron; and as these are phosphates, sulphates, and silex, their respective bases will combine with the metal, which, when once fluid, does not absorb carbon, but rapidly descends into the hearth. In this case we perceive that a certain height of a column of hot coal is required to reduce the oxide; if that column is too low, the iron arrives, in the form of oxide, at the tuyere, and cannot be converted into metal but by the presence of grey iron in the pool of the crucible, the carbon of which will reduce the oxide which may be in the slag. The height of the column of hot coal required will depend on the nature of the ore. If it is a very fusible silicate, such as forge-cinder, a considerable height is necessary, because it will descend rapidly and escape the action of carbon.

In thus analyzing the operation of a blast furnace, we see that, in the one case a very low column of heat, and in the other a very high one, is required. Between these two extremes we find the proper height. Very porous bog ores containing phosphorus, smelt in a narrow, almost cylindrical hearth, 5 feet in height; a red heat is hardly perceived at the boshes. Forge-cinder, by itself, requires at least a column of 25 or 30 feet in height of a red heat; and thus high the crucible ought to be, in order to obtain the necessary intensity of heat. This shows very clearly the principle involved in the construction of a furnace-hearth and the boshes. Where the latter commence, there the smelting of the ore begins, and not elsewhere. But as this rule would cause the crucible to be very high for refractory ores, it and the boshes form one general slope, which may be very high, as the ore requires no preparation in the upper parts of the furnace, and only the fuel is to be freed from moisture.

These principles are not confined to the kind of ore; fuel exerts more or less influence on the height as well as dimensions of a furnace. Hard, dry fuel, such as anthracite, requires little preparation in the furnace, and low stacks will work with it profitably. Coke requires more preparation, and charcoal most; and as a high furnace has a tendency to draw the heat up, it is found necessary to reduce the height of a charcoal furnace, in order to save fuel, by reducing the column of heat, and consequently radiation of heat. In the difference of the height of heat in furnaces, or in the radiation, which is the necessary consequence, may be found the chief cause of the great difference in the consumption of fuel. This accounts for the fact that charcoal furnaces which smelt mild, fusible bog ores, will produce a ton of iron with less than a ton of coal, when anthracite furnaces use from 1·6 to 2 tons and more, and coke furnaces do not work with less than 2 tons of coke, which is equal to 3 or 4 tons of coal, for smelting the same amount of metal.

*Hot Blast.*—The application of hot blast at blast furnaces is general; with few exceptions at

charcoal furnaces, it is done everywhere. In Figs. 699 and 700 we have represented the apparatus as it is most commonly constructed, which may be considered as its best form. In some instances the hot-blast stove is placed near the tuyeres, as shown in Fig. 701; and each tuyere has its own

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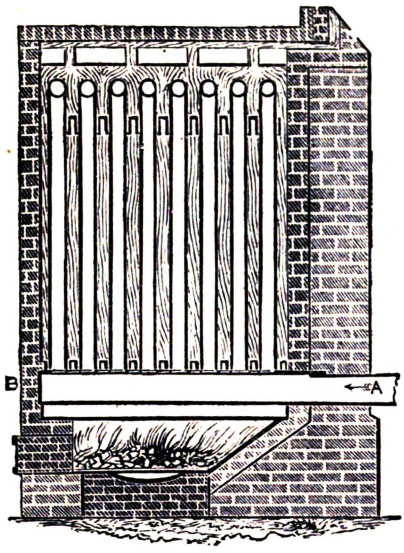


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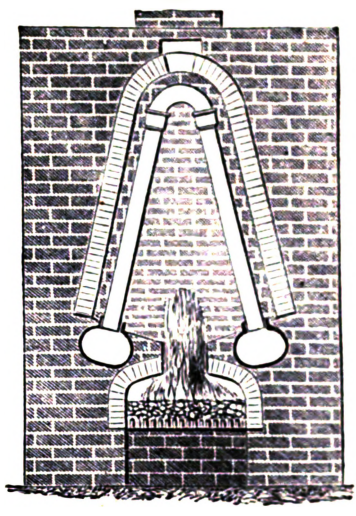

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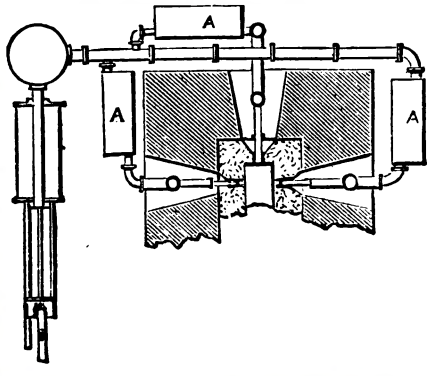


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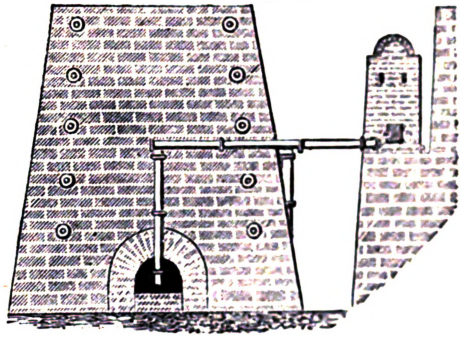

stove, A A A, which enables the founder to heat the blast for one tuyere more than for the other, as its condition may require. At large furnaces it frequently happens that one tuyere does not work so hot as the other, and, in order to remedy the evil, more heat is applied at the cold one.

In general, one apparatus is placed conveniently near to all the tuyeres, and this heats the blast for all of them, however many there may be. In this case the most convenient position is behind the furnace, somewhat elevated above the tuyeres, as shown in Fig. 702. The hot-blast pipes are then above the heads of the workmen, and easily accessible for repairs.

These cases refer to the method of heating the blast with separate fuel, which is not often practised. The most common mode is to heat it at the top of the furnace, or at some distance below it, even as low as represented in the last engraving. The first instance has been represented, Fig. 690; and in the latter, the arrangement takes the form shown in Fig. 703. The waste heat is conducted from the top of the furnace, either in large iron pipes, or in channels of masonry, to that point where the hot-blast stove is located. In some instances we find the stove provided with a

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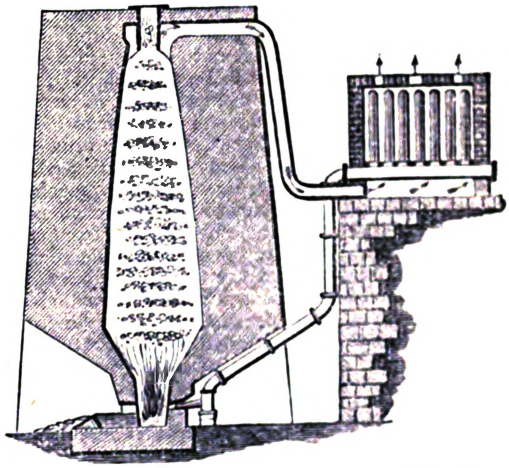

furnace, or grate, for burning coal or wood. This precaution is taken to provide heat by extra fuel, in case the waste heat from the furnace is not sufficient to heat the blast to the degree required. This does not happen at anthracite or coke furnaces, but is confined to charcoal ovens.

At some furnaces we find the hot-air pipes enclosed in wrappings, which consist of articles which are bad conductors of heat; at others, the pipes are walled in, in the rough masonry of the stack. Whatever be the mode of conducting blast, the pipes ought to be spacious, for the increased volume of the hot air, compared with it when cold, causes much loss of power, or pressure, if the pipes are too narrow.

*Effect of Hot Blast.*—The apparently singular effect of hot air in a smelting furnace is chiefly of a chemical nature. The heat introduced by the hot air amounts at best to $\frac{1}{6}$, and in most instances only to $\frac{1}{16}$ of that generated; and still a considerable amount of fuel is saved by it, which at charcoal furnaces amounts to $\frac{1}{4}$, at coke furnaces to $\frac{1}{3}$, and at anthracite furnaces to nearly $\frac{1}{2}$ of that used by cold blast. The immediate advantages are, the quantity of heat introduced, in case that is derived from waste heat, a small increase of temperature, and a fluid cinder, by which flux is saved. The latter effect is in consequence of the absence of the chilling effect of cold air, and a more intimate union of the ingredients. The essential effect of hot blast consists in its facilitating the union of carbon and the oxygen of the blast, by which means carbonic oxide is more readily formed, in which gas carburetted iron may descend without loss of carbon. Cold blast will produce a larger atmosphere of carbonic acid around the tuyere than hot blast, and this gas will not only absorb carbon, but oxidize silicon and iron. As the influence of hot blast on ore is of such a nature as to facilitate the revival of metals, many other substances besides iron ore are reduced, and form an alloy with the metal. To these foreign substances belong particularly those which are in close contact with the particles of iron, such as phosphorus, sulphur, and silex; calcium is often reduced from the limestone used as flux, when the blast is heated beyond a reasonable temperature. By experience it has been found that, for charcoal, a heat beyond 300°, for coke 400°, and for anthracite 500°, is of not much advantage.

The quality of iron smelted by hot blast must naturally be inclined to grey iron, because all the oxygen and other gases being perfectly saturated with carbon, there is no opportunity for the ore to escape being carbonized. But it has been observed, and must naturally be expected, that hot-blast iron is more impure than cold-blast iron. It contains, particularly, more of the basis of silex, because this substance is everywhere associated with iron ore, and is subject to reduction by carbon at a high heat in the presence of iron, and in the absence of carbonic acid. The quality of the metal is, therefore, eminently suited for use in the foundry. It is, on account of the amount of its impurities and the metallic form in which they are present, very fluid, and remains so a long time, which is the cause of its forming grey, tempered castings. Whatever may be the opinion and experience of some engineers, there cannot be any doubt that cold-blast iron with the same amount of carbon as hot-blast iron, and cast into dry moulds, is stronger than hot-blast iron, smelted from the same kind of ore. Hot-blast iron forms a superior foundry iron for small castings, but it is weak in large castings, the cause of which is obvious. The mixture of carbon, impurities, and iron, which causes its fluidity, makes it also a bad conductor of heat; it will not cool so quickly as strong and pure iron, and consequently it is not so liable to crystallization. This iron may be, therefore, a superior foundry iron for small castings; but it must be always inferior to cold-blast for heavy ones, and particularly for the forge.

The large quantity of heat lost at the top of a blast furnace has been the cause of frequent speculations to devise some plan for its use since the earliest adoption of these furnaces. It has of late led to a great deal of controversy, and occasioned much examination of the nature of these gases, as well as of those in the interior of the furnace. The subject is so far settled at present, that it is found injurious to abstract gases lower down from the top than where they consist chiefly of carbonic acid, vapours of water, a little carbonic oxide and nitrogen, and some other substances; in fact, these gases are not abstracted until they cease to be useful in the furnace. We may tap gases from the furnace lower down in the stack; but they are not of more use than those near the top, and such an operation is more or less injurious to the working of the ores. When these gases are abstracted at a height where they cease to be useful, we may term them waste heat; but if we tap lower down they cease to be waste heat; for the highly carbonized combustible gases are essential to the good effects of the furnace, as must be evident from our preceding remarks.

At a variable height, 8 ft. on an average below the top in charcoal furnaces, 8 or 10 ft. in anthracite furnaces, and 12 or 16 ft. in coke furnaces, the gases are of the same, or similar composition. They consist here chiefly of carbonic acid, nitrogen and steam, and some carbonic oxide. It is a mere matter of convenience, so far as regards the furnace, at what precise spot we abstract the gas. Below these various heights it changes suddenly in its composition. It is composed chiefly of carbonic oxide, some hydrogen, nitrogen, and moisture. These are substances which are essential to the reduction of the ore, and which ought not to be removed.

We have already shown the mode of abstracting the waste heat from the furnace. The most common method is by means of a cast-iron cylinder of 5 to 8 ft. in length, as shown Fig. 703 and in other drawings. The depth to which a cylinder is lowered has no effect upon the amount of heat obtained; this is regulated by the distance to which the heat is to be conducted. A long or deep cylinder affords more pressure; consequently the gas may be conducted farther from it. When steam-boilers, or a hot-blast stove, are at the top of a furnace, the insertion of a cylinder is not necessary; in fact, it is of no advantage in any case, for sufficient heat is given out at the top in all instances to heat steam-boilers and hot-blast stoves. In this case the arrangement is such as is shown in Fig. 704. A chimney at the end of the boilers, or at the top of the stove, produces the necessary draught. A plain cast-iron plate with a narrower mouth than that of the brick below, affords a chamber on the top of the fuel. When desired, this aperture in the iron plate may be covered by a door which is occasionally removed for charging fresh ore and coal. This plan works well enough in small charcoal furnaces; but at large furnaces, with a wide mouth, and

whose boilers require a large quantity of heat, the effects are not certain. If any objection exists to the application of an iron cylinder, which may be the case when the top works very hot, an arrangement such as is represented in Fig. 705 is equally effective. It is particularly employed,

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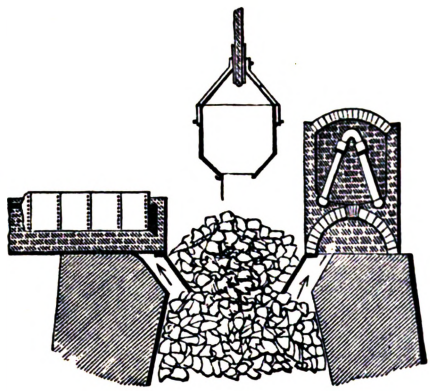

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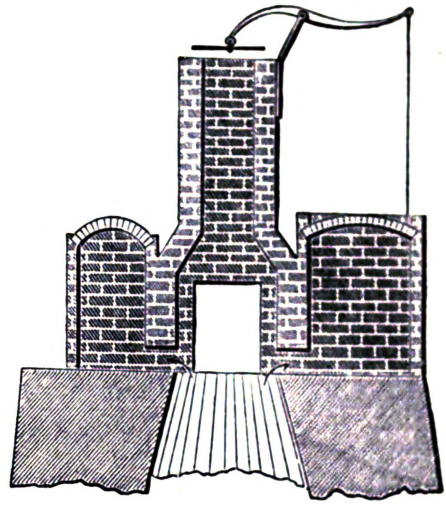

and useful for burning lime, or heating blast. Over the mouth of the furnace a chimney is erected, provided with a damper on its top. Some iron doors, which are opened by pushing the wheelbarrow against them, and shut themselves when it is withdrawn, afford access to the interior for charging. By these means all the heat at the top is saved, and may be conducted to any place where it will be useful.

The amount of waste heat at a blast furnace is very large, but even when tapped low in the stack and burned with the addition of fresh atmospheric air, its temperature is so low that it cannot be employed to advantage for melting, puddling, or welding iron. At the top it produces a high red heat, and at anthracite or coke furnaces a white heat, well adapted for generating steam, heating blast, burning lime or bricks, and similar purposes. In conclusion, we insert some tables, which will be found useful for reference, explaining many things which could not be referred to in this short exposition.

*Charcoal Furnace.*—At a charcoal furnace the following persons are employed:—one founder, two firemen, two fillers, one gutter-man, one coal-drawer, a bank hand, and a horse, cart, and driver, and if there is a *stamping-mill*, or *battery*, a hand to attend to it. This is the smallest number of hands necessary to manage a furnace; generally there is twice that number. When ore is to be broken or roasted, flux to be broken, and similar work to be done, an additional number of hands is required. There are charcoal furnaces which consume 250 bushels of coal to a ton of iron; 200 bushels is an average in the Western States of America. In Western New York, some furnaces smelt a ton of iron, from magnetic ore, to 150 bushels of coal; and in the St. Lawrence district, where specular ore and red hematites are chiefly smelted, as low as 100 bushels of coal are used to the ton of iron. A stack in that region, which operates well, is about 30 or 33 ft. high; 7 or 8 ft. boshes, with a cylindrical part, 2 ft. high, above the boshes; mouth, 31 in., and from that to 36 in. (when an iron cylinder is used it is of the same size); width of hearth between the tuyeres, 22 in., and 32 in. at the top; height of hearth, 5½ ft.; tuyeres, 22 in. above the bottom; the in-wall a curve, as shown Fig. 677, C; such a furnace smelts from 5 to 8 tons a day.

The Siscoe furnace, on Lake Champlain, working magnetic ore, is 44·75 ft. high; 13 ft. boshes; 2 ft. 10 in. hearth, across the tuyere; hearth, 38 in. high: slope of boshes, 64°, with a cylindrical part above the slope of 3½ ft. high; mouth, 4 ft. 3 in. wide. This furnace uses about 160 bushels of coal to a ton of iron; its erection has cost about 30,000 dollars, exclusive of eight kilns for charring wood, which cost an additional sum of 10,000 dollars.

*Anthracite Furnaces.*—The form and dimensions of these vary exceedingly. They are not often above 33 ft. high; from 10 to 18 ft. boshes; 3½ ft. to 5½ ft. across the tuyeres; hearth, from 3 to 5 ft. in height, generally much battered; boshes, from 50° to 70°; top, 5 ft. to 9 ft. in width. A small anthracite furnace produces from 80 to 120 tons of iron, large furnaces from 180 to 200 tons, per week.

*Coke Furnaces.*—These are generally 50 ft. high, and as wide at the base; boshes, 15 ft.; slope, 65° to 70°; hearth, across the tuyere, 4 ft.; at top, 5 ft.; height of hearth, 6 ft., and tuyere above bottom stone, 2 ft. The cost of erection is equal to that of an anthracite furnace; iron made per week is 80 to 100 tons, using 2 tons of coke to 1 ton of iron.

The coal charges at furnaces are always of the same measure—about 15 bushels, more or less. The weight of ore is regulated according to the capacity of the coal for smelting. The number of charges in a certain time, say twelve hours, varies from 12 to 30, according to the quantity of blast injected into the furnace.

The number of blast furnaces in the United States may be estimated at 1200; of which about 100 are anthracite furnaces, 8 bituminous coal furnaces, and a similar number which use coke. The others are charcoal furnaces.

*Description of the Blast Furnaces at Iron Works at Grosmont, by Hiram C. Coulthard, of Blackburn. Taken from the 'Proceedings Inst. M. E.'*—In the Cleveland iron district, where the Grosmont Iron Works are situated, there were, in 1863, 63 blast furnaces in full operation, 17 furnaces not in operation, standing for repairs or other causes, and 11 furnaces in various stages of progress.

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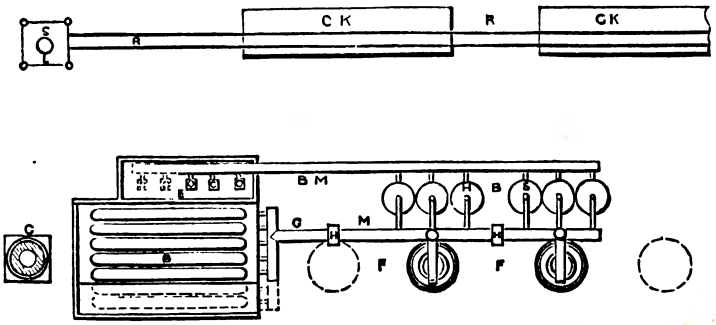


*Reference.*—S L, Steam Lift. C K, Calcining Kilns. R R, Railway. B, Boilers. E, Engines. B M, Blast Mains. G M, Gas Main. F F, Furnaces. H B S, Hot Blast Stoves. C, Chimney.

Grosmont, near the coast of Yorkshire, is situated about seven miles from the port of Whitby, 20 miles from the Durham coalfield, and about the same distance from the lime district of Pickering, whence the supply of lime is derived. Fig. 706 is a general plan of the entire works, which are adjacent to the main line of railway from Whitby to Castleton, joining the North Yorkshire and Cleveland Railway, and thus in connection with the Newcastle and Durham coal and coke districts. A siding from the main line runs into the works.

These blast furnaces are constructed on a very efficient and economical plan. Each furnace is capable of producing 250 tons of pig-iron a week, allowing for stoppage on Sundays. Fig. 707

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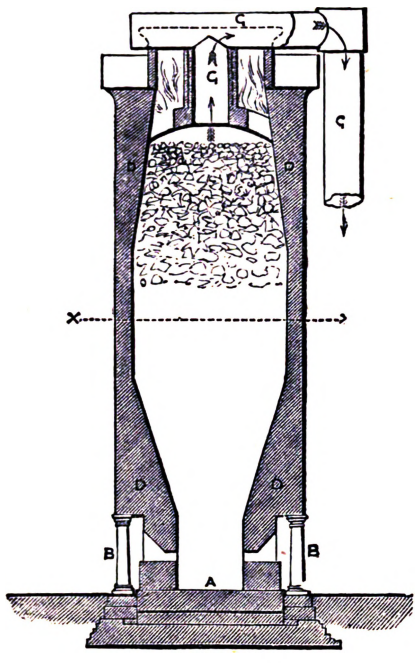


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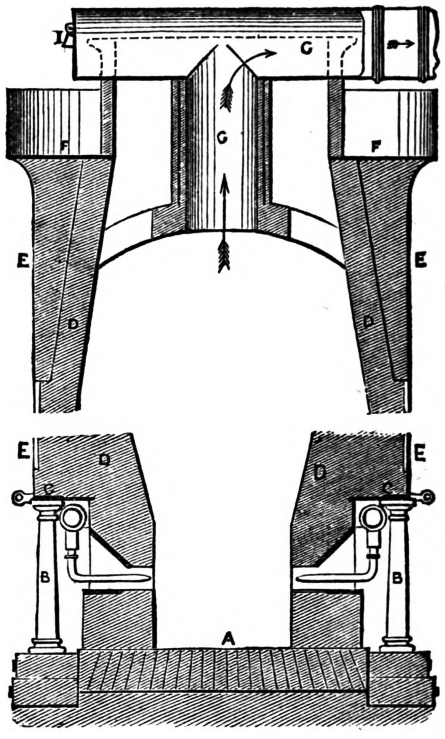
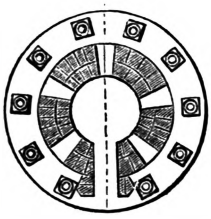



is a vertical section of one furnace, and Fig. 708 shows an enlarged vertical section of the top and bottom of the furnace. Figs. 709 to 713 are transverse sections of the furnace at the tuyeres, tapping-hole, and hearth, and through the body of the furnace.

Each furnace measures 18 ft. diameter at the boshes, and a total height of 63 ft. from ground-line to level of charging-floor. The foundations were dug out to a depth of about 9 ft., to rock on one side, and hard blue clay on the other, the ground sloping in the direction of the dip of the rock. The stone foundations, both for the hearth and casing of the furnace, are shown in the vertical sections, Figs. 707, 708, and consist of ring-courses of masonry built on concrete, about 26 ft. diameter, each course being bound by a wrought-iron ring, 5 in. wide and $\frac{1}{8}$ in. thick, Fig. 708. In the interior of the uppermost ring-course is built the fire-brick hearth A, Fig. 708; the blocks of

which this is formed are shown in plan and vertical section in Figs. 711, 712. These blocks are set in ground fire-clay in a moist state, special care being taken to secure a perfectly homogeneous mass, as the whole of the superstructure of the furnace and its contents, when in working order weighing about 1200 tons, rest upon this foundation. On the top course of masonry the founda-

709.



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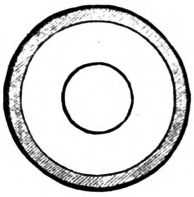

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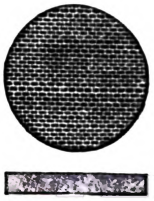


712.



713.

tion-plates of cast iron, 3 ft. 6 in. square and 4 in. thick, are bedded in fire-clay, to which are bolted the cast-iron columns B B, Fig. 708, 17 in. diameter, for carrying the superstructure. These columns are united at the top by a cast-iron ring or cornice C, in segments 3½ in. thick, each segment having a semicircular snug cast on its under-side, which, when the work is joined together, fits into the top of the column B, thus binding the whole of the segments into one ring.

The entire lining of the furnace inside is of refractory fire-brick, D, Fig. 708; the furnace is cylindrical on the outside and entirely cased with wrought-iron plates E, ⅜ in. thick at the bottom of the furnace, and towards the top of the furnace diminished in thickness to $\frac{5}{16}$ in. This casing weighs about 30 tons and costs about 400*l.*, and is now being generally used in the place of the massive stack of masonry formerly used. There are ten cast-iron pillars B for carrying the superstructure, placed at a distance of 7 ft. apart, except where the tapping-hole is situated, where the distance is increased to 10 ft., as seen in Fig. 709. Brackets are cast on these pillars, Fig. 708, for the purpose of carrying the circular pipes that convey the blast and water round the furnaces for distribution to the various tuyeres. There are five tuyeres to each furnace, one of which is shown in longitudinal section in Fig. 714.

714.

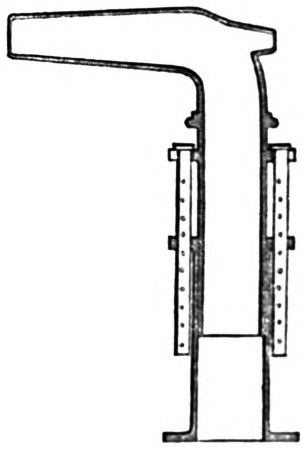


Fig. 713 shows a transverse section of furnace at X X.

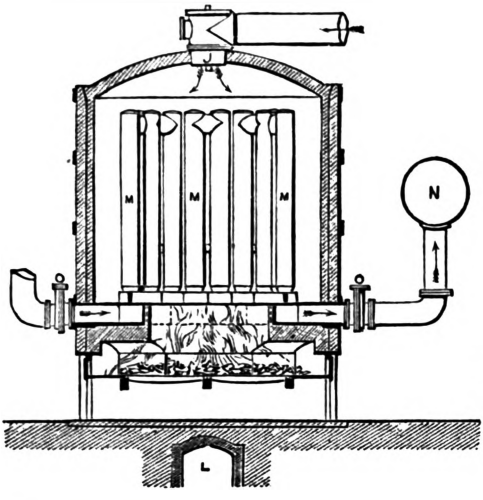
At the top of the furnace a wrought-iron plate-cornice F is fixed, Fig. 708, forming the charging-floor; and the two furnaces are connected by means of two longitudinal wrought-iron girders 4 ft. and 3 ft. deep respectively, the larger one prepared to receive the wrought-iron beams that form the roadway of the incline up which the materials for smelting are drawn by means of a pair of fixed horizontal engines. These girders are united by nine intermediate cross-girders of wrought iron, and, when covered with plates, form the roadway of the charging-floor, having a screen 3 ft. 6 in. high running round for protection.

The throat of the furnace, Fig. 708, is adapted for taking off the waste gas, which is collected in a wrought-iron tube G, 5 ft. diameter, which extends down the throat of the furnace about 5 ft., and is lined inside and cased outside with refractory fire-brick 6 in. in thickness. This tube is fixed to and supported by a crown or dome, built in the throat of the furnace, of specially moulded lumps of fire-clay, supported by six buttresses built of the same material. The crown has six openings formed at the sides for charging purposes, and one opening in the centre, through which the gas passes into the tube G. There is the usual brick chimney at the top of the furnace, with wrought-iron swing-doors corresponding with the openings in the crown. The gas is conveyed from the furnace-top to the boilers and hot-blast stoves by a wrought-iron tube 5 ft. 6 in. diameter, large enough to take off the gas from two additional furnaces; and square boxes, H, Fig. 706, are fixed at intervals along the tube to allow for expansion. A flap-valve, I, Fig. 708, opening outwards for cleaning purposes, is fixed at the end of the tube over the furnace.

Figs. 715, 716, show a vertical section and sectional plan of one of the hot-blast stoves. Three of these are built to each furnace, of common brick made on the estate, lined with refractory fire-brick, and externally bound firmly together by wrought-iron hoops 4 in. wide and ⅜ in. thick, placed at intervals of 3 ft. The stoves are heated by the gas being admitted at the top, J, and a small fire is kept on the grate at the bottom for the purpose of ensuring that the gas is always ignited. Four flues, K K, Fig. 716, pass away from the bottom of the stove to the main chimney-flue L, Fig. 715, which is in connection with the chimney-stack, Fig. 706, of 180 feet height. A simple disc-valve J is fixed at the top of the stove where the gas enters, to cut off the supply of gas from the stove at any time. The pipes M, through which the blast passes, consist of ten pairs to each stove, 12 in. diameter, each pair being arched at the top and united at the bottom by connecting foot-boxes, thus forming one continuous course of pipes for the blast to pass along. The blast enters on one side of the oven, and, after circulating through the pipes M, passes out at the other side into the main pipe N for the service of the tuyeres, as shown by the arrows. A stop-valve O serves to cut off the communication of each stove with the blast-main, which is 5 ft. 6 in. diameter, and thus forms also the blast reservoir. The temperature of the blast is from 600° to 700° Fahr., and the quantity blown by each engine is 6000 cub. ft. per minute, at a pressure of 3 lbs. per

square inch. These hot-blast stoves have been found most effective; from the enlarged capacity of the pipes, the blast is much longer in passing through them, and consequently they are not required to be kept at such a destructive heat.

715.

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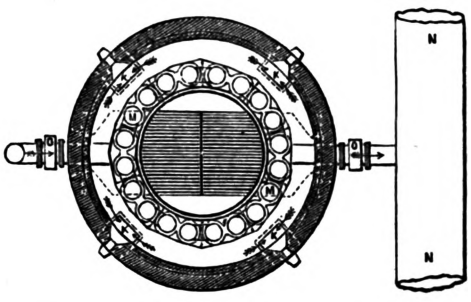



The blast is supplied by three direct-acting high-pressure engines, quick-moving, having air-cylinders 57½ in. diameter, with a stroke of 3 ft. Two engines are sufficient for the work of two furnaces, a third one being provided in case of emergency. The reason for separate engines being used is that in the case of an accident to the blowing-engine, when only one engine is used, the whole of the furnaces are thrown idle. Moreover, the cost of machinery for two furnaces is much less in these engines, taking into consideration the expensive nature of the stonework, and so on, required for the foundation of one large beam-engine. The only foundation required for these engines is about 3 ft. depth of brickwork, with a framework of timber on which to bolt the foundation-plates.

The engine-house is of brick, the roof is formed by the water-tank, which contains the water-supply for the tuyeres, pig-beds, and so on. In the engine-house is fixed a travelling crane, for the convenience of examining any portion of the engines; this is found a most useful appendage. The boilers are five in number, each 73 ft. long by 5 ft. diameter, of the plain egg-ended form, heated by the waste gas from the blast furnaces. They are suspended by means of cast-iron bridges from the top of the boiler seats, and are fed by three donkey-engines, all connected to one pipe over the boilers. The steam pressure is 60 lbs. a square inch above the atmosphere.

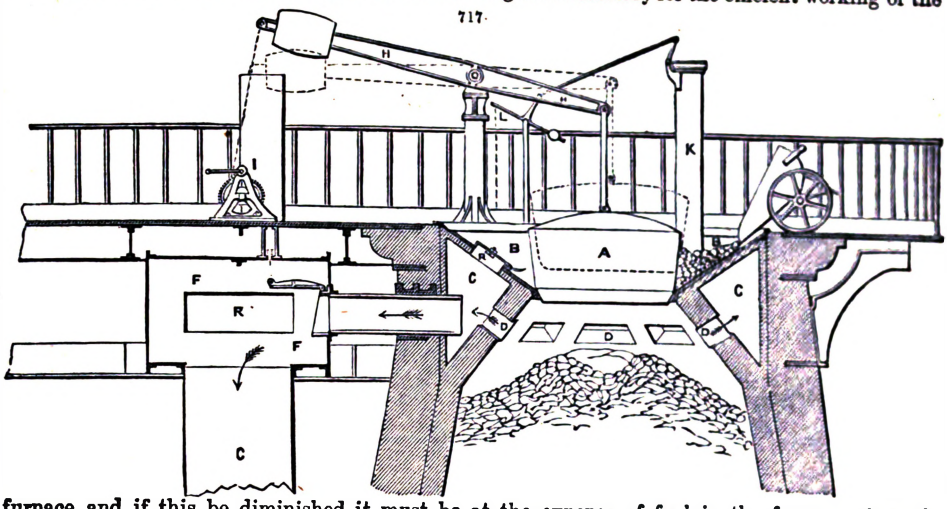
A steam lift is fixed in the works in the position shown S L, Fig. 706, for the purpose of raising the minerals from the line of railway to the top of the calcining *kilns*.

*Description of a Method of Taking off the Waste Gases from Blast Furnaces, by Charles Cochrane.*—In the 'Proceedings of the Inst. of M. E.' for 1860, Cochrane observes, there is no novelty in the fact of taking off the waste gases from a blast furnace; for many methods have been and are at present employed for accomplishing this object. Though Cochrane was unaware of any similar method, he does not desire to claim originality in that about to be described; but as there is such acknowledged diversity of opinion as to the respective merits of different plans, and great difficulty in procuring reliable information on any, it is proposed to give a description of an arrangement which has been in successful operation for some time at the Ormesby Iron Works, Middlesborough. The large waste of fuel from the mouth of a blast furnace where the escaping gases are allowed to burn away is well known, and amounts to more than 50 per cent. of the fuel burnt; hence there is considerable margin for economy, bearing in mind the large quantity of coals consumed in raising steam for generating the blast and the further quantity necessary to heat that blast to the required temperature. In fact, assuming a consumption of 300 tons of coke a week to make 200 tons of iron, about 100 tons of coal would be required to generate steam and heat the blast. Taking off the gases from one furnace under such conditions does, according to actual experiment, furnish gas equivalent to upwards of 150 tons of coal a week. This is obviously an important matter where coals are expensive.

The blast furnace is alternately charged with coke, ironstone, and limestone, in proportions depending upon the quality or "number" of iron desired. The arrangement of these materials in the furnace is generally deemed important, though it admits of considerable latitude without any appreciable alteration in the working of the furnace. Thus it does not seem to be of any importance whether the charge of coke be 12 cwt. or 24 cwt., the amount of load of ironstone and limestone being in the same proportion of 1 to 2. The chief point, if there be one, to be gained in the arrangement of the material is, to distribute it pretty equally over the furnace, not allowing all the large material to roll outwards, and the small to occupy the centre of the furnace, or *vice versâ:* for it is supposed the ascending gases will pass through the more open material of the furnace to the injury of the closer; thus the two reach the active region of reduction in different states of preparation, and the operations of the furnace are interfered with. To provide for this contingency, which is met in an open-topped furnace by filling at the sides at three, four, or even six points of the circumference of the throat, allowing the material to slide inwards 2 or 3 ft. on a sloping plate, it was considered expedient in the present instance to make the filling aperture as large as practicable: it was therefore made 6 ft. 6 in. diameter, as shown in Fig. 717, so that the material tends to arrange itself in a circle a little outside the centre, thus correcting the tendency of large material to roll outwards by causing a similar tendency to roll towards the centre also.

This point is gained by one of the simplest methods in use for closing the top of a blast furnace, where a cone is used to lower into the furnace for filling; but it is secured at the expense of the height of material in the furnace. A certain height is necessary for the efficient working of the

717.

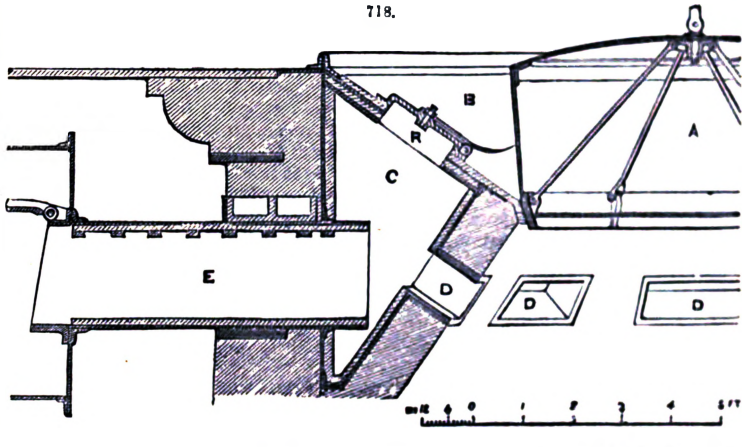



furnace, and if this be diminished it must be at the expense of fuel in the furnace, since the absorption of heat from the gases depends on the height of material through which they have to pass up: if this be diminished, the gases issuing from the throat of the furnace will escape at a higher temperature; if increased, at a lower.

But there is an important difference to consider in the conditions of a closed and an open-topped furnace, to which Cochrane is not aware that attention has hitherto been drawn; a difference which acts somewhat in favour of the open-topped furnace. The working of the furnaces themselves seems to show that an open-topped furnace is less sensitive to irregularities of moisture in the material, quantity of limestone, size of material, and so on, which can be accounted for only by the fact that the open-topped furnace has the advantage of a large amount of surplus heat, due to the combustion of the waste gases at its throat, which serves to dispel moisture and calcine the limestone, and helps to warm up the large pieces of ironstone: all of which operations in the close-topped furnace are effected only at a lower point of the furnace, thus necessitating a larger consumption of coke. With the same proportion of ironstone to limestone, it has been found to require about 10 per cent. more fuel to produce the same number or quality of iron in a close-topped than in an open-topped furnace. In the close-topped furnaces the gases pass away at a temperature of about 450° Fahr.; whilst in the open-topped a temperature of between 1000° and 2000° is generated in the throat of the furnace by their combustion.

In comparing the extra quantity of coke consumed in a close-topped blast furnace with the saving in coals for the boilers and hot-blast stoves, it is obvious that the economy to be derived by taking the gases off depends on the comparative value of coke and coal. In the Middlesborough district, where coal is expensive, it is an undoubted source of economy; where coke is very dear, however, and small coal can be obtained at a mere nominal cost for boiler and stove purposes, the use of the waste gases would possibly do little more than compensate for the outlay involved. Here, no doubt, is one source of the variety of opinion entertained in various districts as to the advantage of taking off the gas. Cochrane's experience at Middlesborough has been, that the waste gases can be taken off without affecting the quality of the iron produced, though at the expense of more fuel.

718.

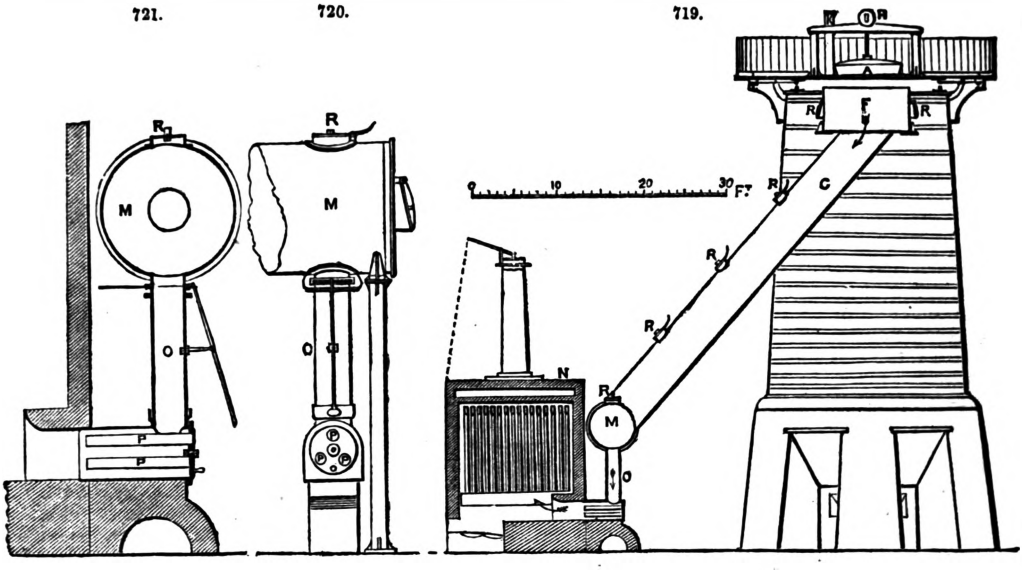



The mode of closing the furnace-top and taking off the gases at the writer's works is shown in Fig. 717. The top of the furnace is closed by a light circular wrought-iron valve A, 6 ft. 6 in. diameter, with sides tapering slightly outwards from below, as shown enlarged in Fig. 718, to admit of being easily drawn up through the materials, which are tipped at each charge into the external

space B. To prevent excessive wear upon the body of the valve, shield-plates are attached at four points of its circumference, against which the material strikes as it rolls out of the barrows. An annular chamber C encircles the throat, triangular in section, into which the gas pours through the eight orifices D D from the interior of the furnace, and thence passes along the rectangular tube E into the chamber F. At the extremity of the tube E is placed an ordinary flap-valve opened by a chain, by means of which the communication between the furnace and the descending gas-main G may be closed. The valve A is partially counterpoised by the balance-weight at the other extremity of the lever H, and is opened by a winch I when the space B is sufficiently full of materials. At the time when the blast is shut off for tapping the furnace, the gas escapes direct into the atmosphere through the ventilating tube K, which is connected by levers L with the blast inlet-valve below.

Fig. 719 shows the connection between the furnace-top and the hot-blast stoves to be heated by the waste gases, which pass down the descending main G into the horizontal main M running parallel and close to the line of stoves N, from which descend smaller pipes O to each stove, as shown in Figs. 720 and 721. The supply of air for burning the gas in the stoves is admitted

721. 720. 719.




through the three tubes P, and can be regulated at pleasure by the circular slide closing the ends of the tubes, which has an aperture corresponding to each tube, and is planed on the rubbing-face, as is also the surface against which it works, in order that the slide may be sufficiently air-tight when closed. The ignition takes place where the air and gas meet, the ignited gas streaming into the stove and diffusing its heat uniformly over the interior. An important element in the working of an apparatus of this description is to provide for explosions, which must take place if a mixture of gas and air in certain proportions is ignited. To provide for this contingency, escape-valves R are placed at the ends and along the tops of the main tubes G and M; but to prevent explosions as far as possible, the ventilating tube K, Fig. 717, is used at the top of the furnace, connected with the blast-valve at the bottom, so that when the valve is closed, as at casting time, the act of closing opens the ventilating tube, and allows the gas to pass away direct into the atmosphere. The gas would otherwise be in danger of slowly mixing with air passing back through the stoves or otherwise gaining access into the tubes, and would thus give rise to an explosion. Until the ventilating tube was provided, it was necessary to lift the valve A closing the mouth of the furnace when the blast was taken off, otherwise slight explosions took place from time to time.

In the use of Durham cokes in the blast furnace, an inconvenience arises from the large deposit which takes place in the passage of the gas from the furnace and in the stoves and boilers. Under the boilers this deposit is a great objection, as it is a very bad conductor of heat, and needs to be frequently removed: in the stoves it is not so objectionable, though these need a periodical cleansing. The deposit does not arise altogether from the cokes, it is true; and it may be interesting to know its composition, which is as follows:—

| | |
|---|---|
| Silica | 18·86 |
| Carbon | 16·14 |
| Alumina | 13·87 |
| Sulphate of lime | 13·61 |
| Lime | 11·01 |
| Protoxide of zinc | 10·31 |
| Peroxide of iron | 9·01 |
| Protoxide of manganese | 2·56 |
| Potash | 2·13 |
| Protoxide of iron | 1·25 |
| Magnesia | 1·25 |
| Chloride of sodium | 0·60 |
| | 100·60 |

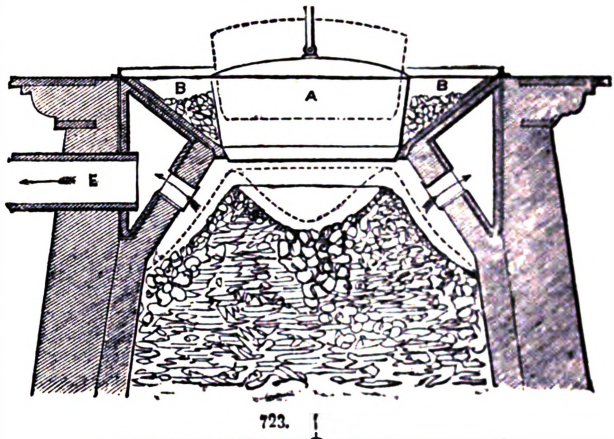
At a temperature of upwards of 3000° this mixture melts in a yellowish slag, dispelling the zinc; but there are no signs of fusion at the temperature produced by the ignition of the gas in the stoves, which must roughly approximate to that of melting iron, from the results of a few experiments made to ascertain this point: though thin pieces of cast iron were not fairly melted down, they reached the rotten temperature, which is only a few degrees below melting, and gave further signs of nearly melting by throwing off sparks when quickly withdrawn from the stoves and struck smartly against another object.

C. Cochrane says, that he has heard it asserted that the closing of the top of the furnace is the source of mischief to its working by producing a back-pressure in it. Under ordinary circumstances, with the furnace-top open, the blast enters the tuyeres at a pressure ranging from 2½ to 3 lbs. a square in. In the present close-topped furnace there are eight outlet-orifices D, Fig. 717, each 2 ft. by 1 ft., giving a total area of 16 sq. ft. for the passage of between 5000 and 6000 cub. ft. of gas per minute, raised to a temperature of 450° Fahr.; and the actual back-pressure of the gas, as measured by a water-gauge inserted into the closed top of furnace, is from ½ to ¾ in. column of water, or about $\frac{1}{40}$th or $\frac{1}{50}$th of a lb. the sq. in., an amount so trivial as compared with a pressure of from 2½ to 3 lbs. as to be unworthy of notice. Of course, if the tubes are contracted in size, a greater back-pressure will be produced; and it is quite possible that where attention has not been paid to the circumstance, the back-pressure may have interfered with the working of the furnace by preventing the blast entering so freely.

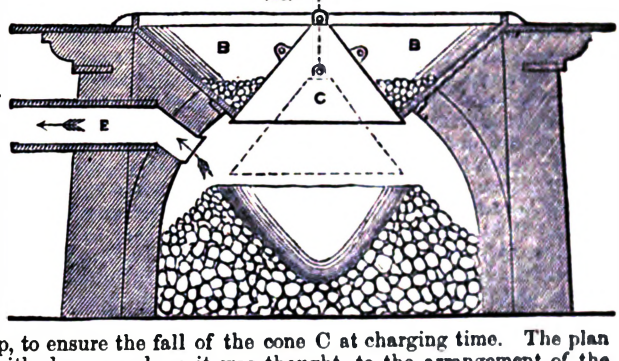
As regards economy in the wear and tear of hot-blast stoves of the ordinary construction, there can be no question the pipes last much longer when heated by gas, provided the temperature of the stove be carefully watched to prevent its rising too high; whilst the value of the same heating-surface compared with its value when coals are used is greatly increased, owing to the uniform distribution of the ignited gases throughout the stove. In the use of the gases at Cochrane's works, this economy of surface is such that two stoves heated by gas will do the work of a little more than three heated by coal fires.

*On the Working and Capacity of Blast Furnaces*, in the 'Proceedings of the Inst. M. E.' (1864), C. Cochrane further observes,—referring to Fig. 722, which shows the original construction of closed-top and lifting-valve for charging, the materials for the charges being filled into the exterior space B surrounding the charging-valve A, which is drawn up into the position shown by the dotted lines for allowing the materials to fall into the furnace; while the gas is taken off from the furnace-top by the passage E, —that the usual plan of closed-top adopted in blast furnaces is that represented in Fig. 723, in which it will be seen that the materials are filled in against a lowering-cone C, placed in the throat of the furnace, which on being lowered into the position shown dotted, permits their fall into the furnace. The tendency of the material in this case is to roll outwards from the charging-cone to the side of the furnace, and thence back again to the centre, as shown in the drawing.

722.




723.



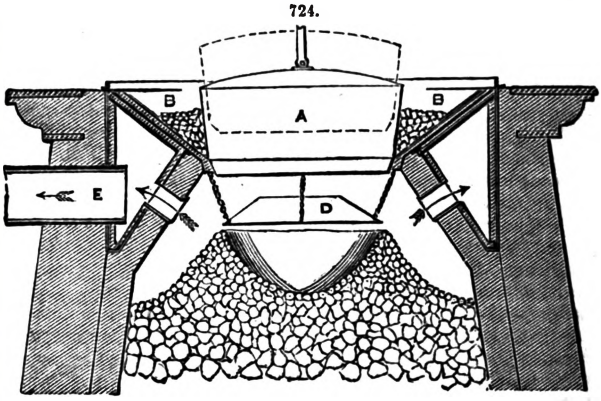

It was thought at the time of adopting the plan shown in Fig. 722, that the height of the materials carried by the same furnace would be increased, and that a corresponding economy in consumption of fuel would result, owing to the circumstance that where the plan shown in Fig. 723 is adopted, the level of the materials must always be maintained at a certain distance below the top, to ensure the fall of the cone C at charging time. The plan shown in Fig. 722 was devised with due regard, as it was thought, to the arrangement of the materials in the furnace; and it was intended that they should arrange themselves as shown by the dotted line in that drawing, part of the larger material rolling to the outside of the furnace and part to the centre.

As long as the furnace could be kept so full as to ensure the arrangement of materials shown by the dotted line in Fig. 722, there was no reason that it should not work uniformly; but the practical result was that it was found impossible to keep the furnace sufficiently full to secure the distribution of the materials in the manner intended. The level of the surface of the materials was generally below that intended, the consequence of which was that the material on falling into the furnace was shot into the centre, from whence the largest pieces rolled outwards, and the

whole charge arranged itself as shown by the full line in Fig. 722. The result of this was irregular working of the furnace over a period of many months, during which an explanation of the irregularity was in vain sought for. At one time it was thought the back-pressure of the escaping gas had something to do with the irregularity; at another the cause was sought for in the difficulty of keeping the hopper-valve A of the furnace tight, and the necessity for using small material around the valve, as a kind of lute between every charge, to prevent the escape of the gas; until it occurred to C. Cochrane that the arrangement of the materials in the furnace was the sole explanation of the difficulty, and that as all the material was shot into the centre of the furnace, the small pieces would remain there, whilst the large would roll to the outside. Believing that it was of great importance, in order to secure uniform results, that there should be a uniform distribution of the heated gas from the hearth over the entire horizontal area of the furnace at each stage of its height, he considered that the effect of any small material being collected in any portion of the area would be to obstruct the passage of the gas at that part, and so prevent that portion of the material from being heated to its proper degree of temperature.

Deeming this to be the explanation of the irregularities experienced in the working of the furnace, Cochrane devised a method of distributing the material so as to prevent such a result, by the introduction of a frustum of a cone D, Fig. 724, suspended inside the throat of the furnace, which was found to be all that was necessary. The materials then arranged themselves in the desired manner, as shown in Fig. 724; and the result has since been a perfect uniformity in the working of the furnace. Where previously a yield of foundry iron from the same furnace could not be relied upon for more than about 24 hours at a time, and the annoyance was incurred of the furnace suddenly changing to white iron, the production of white iron, except when desired, is now unknown. A consideration of these facts will lead to a fair estimate of the importance of the arrangement of the materials in a blast furnace. Anything that opposes the free passage of the ascending heated gas at any part of the furnace must direct the gas into another channel, and the material thus left insufficiently acted upon finds its way into the hearth at a low temperature, and white iron is the result.

724.




The effect produced on the distribution of material by this internal frustum of a cone is obviously similar to that of the ordinary lowering-cone when lowered, shown in Fig. 723; and the latter has now consequently been finally adopted at the Ormesby Iron Works as the permanent form of the arrangement, and is now being carried out there.

The most perfect action of a blast furnace C. Cochrane conceives to consist in the development of the highest temperature needed for the production of the required quality of iron, in a layer or stratum as little removed from the tuyeres as possible; and the gradual absorption of the heat from the ascending gas by the materials through which it passes, until it leaves the throat of the furnace at the lowest possible temperature. Anything which tends to cause a more perfect absorption of the heat developed in the hearth, or to lower the level of the region of highest temperature in the furnace, will thus be beneficial.

With regard to the absorption of the heat from the gas, it is obvious that the hotter the temperature at which the gas escapes, the more wasteful must be the effect; and theoretically the height of a furnace should be increased until the temperature of the escaping gas is reduced to that of the materials on their introduction into the furnace-top. This is the theoretical limit to the height of a blast furnace: but it must not be forgotten that the less the difference in temperature between two bodies, the less rapid is the communication of heat from the hotter to the cooler; hence for the absorption of the last few degrees of temperature from the ascending gas a much greater height of material is necessary than where the gas and the material differ more widely in temperature. Already with 50 to 60 ft. height of blast furnace in the Middlesborough district the temperature of the escaping gas does not exceed 500° to 600° Fahr.; and it is a question to be answered only by experiment, how far the gain from the heights of 70 to 75 ft. already accomplished at Middlesborough, and further heights of 10 or 20 ft. additional that are contemplated, will compensate for the extra work in raising the materials to the additional height and for the more substantial plant required. In the direction of height there is unquestionably on this account a limit which will speedily be attained; supposing the limit be not previously determined by the necessity for increased pressure of blast and by the increased difficulty in working the furnaces.

*Taking off the Waste Gas from Open-topped Blast Furnaces, by George Addenbrooke.*—We take the succeeding account of this method from the 'Proceedings Inst. M. E.':—Writing in 1865, Addenbrooke observes that the utilization of the waste gas from blast furnaces has now become not only an accomplished fact, but a great commercial success, and consequently an important part of furnace management. This gas, or rather mixture of gases, issues in large quantities from all the interstices between the last charge of materials in the furnace-throat; and it passes off with such rapidity as to prevent a sufficient mixture of air taking place to render it inflammable until it has risen to some little height above the top of the materials in the furnace-mouth. As soon, however,

as this mixture of air takes place, a very considerable portion of the gas is consumed, in the case of the ordinary open-topped furnaces that do not utilize the waste gas. This combustion develops a great amount of heat; and the question therefore arises, how can the waste gas be made further useful, without in any way injuring the yield, the working of the furnace, or the quality of the iron made; for if any injury were occasioned in either of the above respects by taking off the waste gas, the utilization of the gas ought certainly not to be attempted. It is evident that there must always be an escape of surplus gas from the top of the materials in the furnace-throat, from the consideration that the heat in the lower part of the furnace distils off the gas from the fuel in the upper part; and this gas, not meeting with a supply of oxygen inside the furnace, passes up unconsumed to the furnace-mouth, where, upon mixing with the external air, it burns away to waste, unless taken off previously in order to be usefully burnt elsewhere.

The utilization of the waste gas has been extensively carried out in two different modes, each capable of being applied and worked in several different ways. The one mode is known as the Close-top system, and the other as the Open-top system.

Addenbrooke was of opinion that the waste gas ought to be utilized for the following reasons, namely, that a furnace would work to better yield where the gas was utilized, and with greater regularity as to the quality of iron made; and that there would be a very considerable saving in repairs to hot-blast stoves and boilers by heating these with the waste gas, together with greater regularity in the heat and pressure of the blast, because of a more even temperature being maintained under the boilers and in the stoves; while there would also be a considerable saving in wages, and the men would be made more regular in charging the furnace.

The principle upon which the waste gas is taken off in the case of the close-topped furnaces is that, by keeping the furnace-top closed, the gas must necessarily pass away through any openings which are made for its escape, and may thus be made to travel even to a distance of more than a quarter of a mile from the furnace, as is done at the Dowlais Iron Works. In the open-topped furnaces the idea is that, after the gas has done very nearly all its work in the furnace, on arriving within about 5 ft. of the top of the materials in the furnace-mouth the greater part can be drawn off from the furnace by applying a mild suction, and employed to advantage for heating purposes elsewhere; at the same time, as no considerable amount of force is used for drawing off the gas, either by the suction of a chimney or otherwise, all surplus gas generated in the furnace beyond the amount drawn off escapes at the open top of the furnace, by passing up through an average of 3½ ft. depth of charged materials above the point of taking off the gas.

The open-topped plans of taking off the waste gas may here be divided into two classes:—those taking off the gas at a less depth than 5 ft. below the top of the materials in the furnace-throat; and those taking it off below that level. In the former the gas is taken off with due regard to the effect on the yield and working of the furnace; while in the latter the utilization of the gas is made the chief object.

In order to carry out the utilization of the gas without risk of interfering with the successful working of the furnace, it is of very great consequence not to take off the whole of the gas, but to leave a certain portion always to escape at the furnace-mouth, so that it may continue the process of preparing the newly-charged materials, and begin to dry and warm them immediately upon their being charged, and also prevent any downward current of air taking place from the furnace-top. Such a downward current of air must necessarily take place frequently, where the whole of the gas is drawn off; as the chimney-power requisite for this purpose would be quite sufficient to draw down the air through the average depth of 3½ ft. of materials in the furnace-throat above the gas-openings, at any time when there was not an ample supply of gas to be drawn off. The result would then be that where the ascending gas and the descending air met in the furnace a bright flame would be produced, which taking place amongst the fuel must occasion a very serious loss, by causing combustion of the fuel before it reaches the part of the furnace where its combustion is useful; and it appears doubtful whether fuel thus once lighted would not continue smouldering the whole of the way down in the furnace. On the other hand, if the fuel is properly covered in the upper part of the furnace by a sufficient depth of materials, so as to be protected from the air, Addenbrooke doubts whether it will begin to burn till it reaches the zone of fusion, where it then changes from a mere highly-heated state to one of active combustion caused by the presence of air supplied from the tuyeres. He believes that in the fact of covering up the fuel, without ignition being allowed to take place, lies one of the chief sources of saving in the yield of the fuel; and he considers that it is this alone, in the close-topped furnace, which to a very great extent makes up for the loss of yield of fuel that must inevitably result from the use of the close-topped system with its consequent back-pressure. This saving, however, is more than counterbalanced by the fact that neither drying nor warming nor any other preparation of the materials can be carried on in the close-topped furnace except by the heat of the gas coming up from below.

Were it not for the back-pressure produced in the furnace by a closed top, this system would doubtless work to a much better yield than the open top; but the entire prevention by the closed top of any drying or warming of the materials taking place until they have descended some distance within the furnace is a serious objection, in G. Addenbrooke's opinion, to the close-topped plan; whilst, on the other hand, in a well-worked open-topped furnace the preparation of the materials begins at once upon their being charged. Moreover, there is no way of so regulating the driving of a furnace or rate of descent of the materials in the interior as that in every hour the furnace shall take the same quantity of blast; but whenever the steam-pressure happens to rise above the average, causing the engine to force more blast into the furnace, or whenever the materials happen to lie more open in the furnace, or to be drier, an increased driving of the furnace will be occasioned, which will give an increased production of gas to pass off from the furnace. As this larger quantity of gas has in the close-topped furnace to pass off through the same openings which previously carried off a smaller quantity, the result must be an increase of the back

pressure in the furnace; whereas with an open top the surplus gas readily escapes at the mouth of the furnace, without producing any back-pressure inside the furnace. Another objection to the closed top is that the pressure coming from the lower part of the furnace will carry off with it from the furnace more dust than would be drawn off by suction.

The requirement in the utilization of the blast furnace waste gas appears therefore to be an open top where the fuel can be buried or covered, without its being ignited to any material extent either by the escaping gas, or, worse still, by the gas being drawn off so completely from the furnace-throat that air is drawn down also through the materials, causing a hidden fire to be raging beneath the surface of the materials while everything seems to be going on well. Addenbrooke states that he has frequently seen the gas drawn off so completely that a man could walk inside the mouth of a large furnace while the blast was on; but experience shows that such a state of the furnace-top is altogether wrong, and if ever it occurs, the main gas-valve ought at once to be closed sufficiently to ensure some gas passing off at the furnace-top, in order to begin the preparation of the materials and prevent any downward current of air.

The level at which the gas is taken off from the furnace is a most important point, as in effect the working height of the furnace nearly terminates at the level where the gas is taken off. The most satisfactory working that Addenbrooke has known of a blast furnace has been where the gas was partially and not wholly taken off, and at a depth of 4 ft. 6 in. below the top of the materials. In one case that came under his experience, one of Darby's bells was used very successfully for a considerable time, taking off the gas at a depth of 4 ft. 6 in. below the top; but when it became necessary to change it, the new bell was inserted to a depth of 5 ft. 6 in., in order to give the fillers a little more range of level. This was, however, found to work so much less satisfactorily, that it was altered back again to the original depth of 4 ft. 6 in.

The very great sensitiveness of a furnace to the least lowering of its working height is undoubtedly the cause of more than one-half of the mottled and white iron that is made where grey forge or forge-iron was expected. The change is usually caused by delay in filling, most frequently at night, when the men often neglect their work, and allow the furnace to drive, so that the surface of the materials is lowered a considerable distance; and the effect is then observed about three casts later by the production of mottled or white iron. The worst consequence of this neglect is that the furnace manager then finding white iron made, probably alters the burden at once in order to correct the fault; and, after charging it up to the next casting time with either less ore or more fuel, he probably finds this next cast all right, and therefore alters the burden back again; but in another cast or two comes the iron made from the lighter burden, rather too grey to suit the purposes it is wanted for. With a closed top there can be no check upon irregularity in filling, day or night, except by constantly watching the filling. But in an open-topped furnace, where the gas is taken off through openings not lower than 5 ft. below the top of the materials, if the filling were delayed more than half-an-hour, the greater portion of the gas would begin to escape at the furnace-mouth instead of being drawn off through the gas-openings, as the surface of the materials would be lowered nearly to the level of the gas-openings. The fillers' neglect would then be detected by an increased flame from the furnace-mouth, and by the supply of gas to the boilers and hot-blast stoves falling short; and they would be recalled to their duty by the risk of all coming to a standstill from stoppage of the blowing engine.

This great sensitiveness of blast furnaces as to being kept charged full appears to suggest strongly the doubt whether the Staffordshire furnaces are now as high as the fuel would allow of their being worked profitably; and whether a gain of yield would not be found to result from raising the furnaces. The present height of from 40 to 50 ft. in Staffordshire has been increased in the Cleveland district up to 80 ft. and more, and it is considered the limit of height has not yet been arrived at in that district. There is no doubt that the Staffordshire fuel would not stand any very considerable increase of height, on account of its friability; but it would at least be desirable to ascertain by trial whether some increase of height would not be beneficial.

The result of the previous inquiries in which Addenbrooke was engaged as to the best mode of utilizing the waste gas from blast furnaces was the adoption of the open-topped plan, with Darby's bell inserted in the neck of the furnace to a depth of 4 ft. 6 in. below the surface of the materials. This plan was applied to two furnaces at Darlaston; and in carrying it out the special points attended to were to provide a large gas-main, a large chimney, and large flues to the chimney. For this purpose the gas-mains were made 5 ft. diameter, the chimney 10 ft. diameter inside throughout, with a height of 160 ft., and the main flues to the chimney very large, 5 ft. high to the crown of the arch and 4 ft. 6 in. wide; and experience has shown that these dimensions are none too large.

The two furnaces continued at work on this system till September, 1864, when the heavy cost of repairs and renewals, with the consequent stoppages and loss in wages, led G. Addenbrooke to design the plan which is shown in Figs. 725 to 731. Fig. 725 is an outside elevation of the furnace to which this system is applied. Fig. 726 is a vertical section of the same furnace, showing the gas-openings A A from the furnace into the neck-flue B, and the gas branch-pipe with stop-valve C for connecting or disconnecting this furnace from the range of gas-main. Fig. 727 is a sectional plan of the furnace taken through the gas-openings A A and neck-flue B. Fig. 728 is an enlarged section of the furnace-top; and Figs. 729, 730, 731, show a vertical section, outside elevation, and sectional plan of one of the segmental boxes or gas-openings.

These gas-openings or boxes are made of cast iron, and allows of the openings being made so wide that their combined area of passage is amply sufficient for the passage of the gas, without the depth of the opening being more than 15 in.; in consequence of which they do not require to be inserted lower than about 5 ft. down, and still leave a fair height of 4 ft. above them for variation in the level of the top of the materials charged. The boxes are cast very strong, as shown in Figs. 729 to 731, and the openings through them are made at such a slope that nothing except very light dust can be carried through them by the gas in regular working, unless it be a bit of

material thrown over by one of the slight explosions that occasionally take place where any raw minerals are used in the furnace. The boxes are placed close together side by side, so as to form

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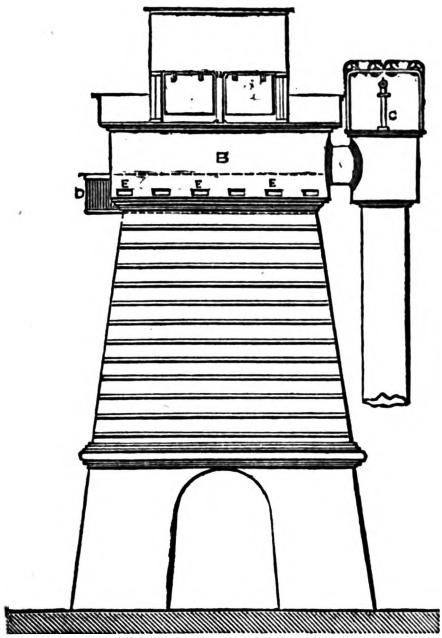


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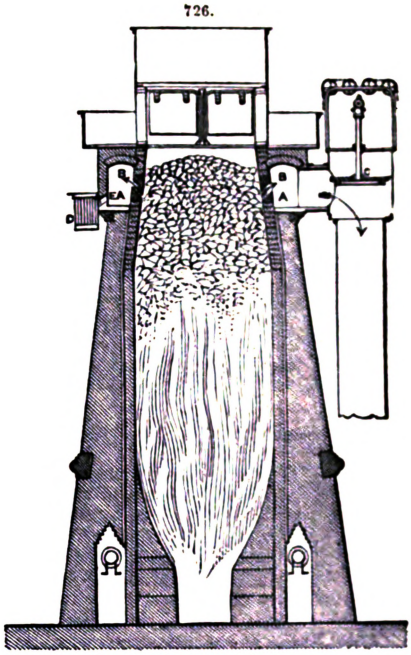


a continuous ring of openings round the furnace, as shown in the plan, Fig. 727, having the lower end of the slopes opening into the furnace and the upper end opening into the large external gas-flue B, Fig. 728, which surrounds the neck of the furnace. These castings take the place of so many courses of lining bricks, and after they have been fixed, the lining fire-bricks are continued above them to the top of the furnace. Considering their strength and situation, the castings appear likely to be almost permanent. As they stand flush with the face of the lining, the whole area of the throat of the furnace is left free for charging; and when the furnace is full, and any portion of the gas passing off at the surface of the materials, no damage can be done to the openings or any part of the gas apparatus. In case of the top of the materials sinking below the gas-openings, any damage is prevented by shutting the gas-valve C at once, when the whole of the gas will be burnt at the mouth of the furnace, but without injury occurring to any part of the apparatus, as is unavoidably the case with the wrought-iron gas-main proceeding from a bell inserted in the top of the furnace.

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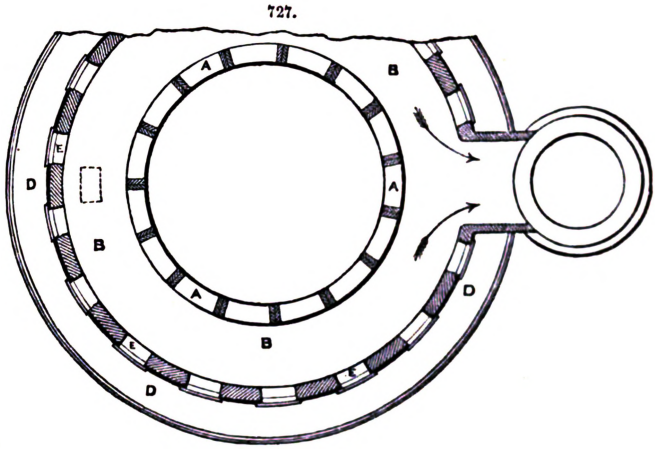


The large gas-flue B surrounding the neck of the furnace is lined with fire-brick, and is 4 ft. 3 in. high to the crown of the arch, by 3 ft. mean width. The outside of the furnace from a little below the bottom of the flue upwards is cased with wrought-iron plates, to which is fixed a light iron gallery D for the convenience of cleaning out the flue B. A series of openings E E are made in the outer side of the flue all round, as shown in the plan, Fig. 727, which are closed by pieces of boiler-plate, daubed with moistened fire-clay, and held in their places by crossbars and wedges; by means of these the whole of the neck-flue can be cleaned out in a few minutes any time that the blast is off the furnace. The bottom of the flue is placed at a lower level than the bottom edge of the gas-openings A A, Fig. 728, in order that the dust carried over with the gas may be allowed to accumulate in the flue, so long as it does not interfere with the gas-openings, and it can be easily cleaned out when required. Experience of the working of this plan of furnace-top proves that, from the increased area of the gas-openings as compared with other plans, the gas does not pass nearly so rapidly out of the furnace, and, consequently, has not the power to carry nearly so

much dust into the flue. The sectional plan, Fig. 727, shows that there are fifteen gas-openings A A round the neck of the furnace, 23½ in. wide and 11½ in. high on the square, each giving 270 sq. in. clear opening, making a total area of 4050 sq. in. for drawing off the gas; whereas the single central opening of the bell of 4 ft. 6 in. diameter previously worked in the same furnace, which was as large a size as could be conveniently used, gave an area of only 2290 sq. in. for drawing off the gas,

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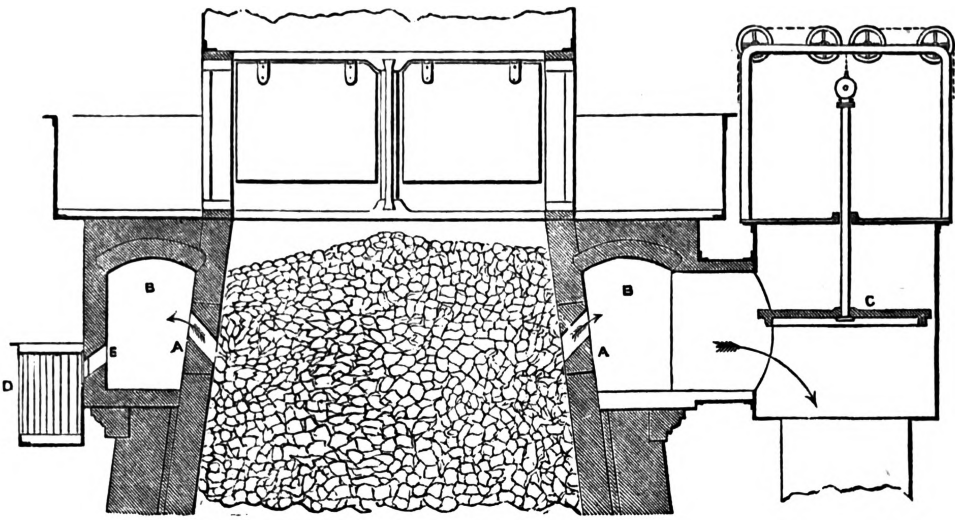


or only 56 per cent. of the area now obtained with the present neck-openings. As the gas-openings give a total area of 4050 sq. in. for the passage of the gas, while the descending gas-main supplied by them being 4 ft. 6 in. diameter has an area of only 2290 sq. in., the velocity of the current of gas through the openings is necessarily only half what it would be where a bell or centre opening is used for drawing off the gas, as in the latter case the gas-opening to the furnace cannot be made of larger area than the descending gas-main of 4 ft. 6 in. diameter.

Notwithstanding the temporary kind of construction that was adopted for trial in the first furnace, the gas-openings made with only 2-in. cast-iron plates lasted more than a year, and stood some of the severest treatment that a furnace-top can be exposed to, in consequence of a sort of fuel being tried at one time which proved a total failure, and with which the furnace was unable to drive at all; and consequently for two days the whole throat was at a red heat. It was expected that when the furnace did drive below where the openings had been, they would be found to have given way. They had not, however, completely given way in any instance; and, though the plates were very much bent, they remained at work a great part of a year afterwards. Their standing so well is to be attributed to their position, in the outside of the furnace instead of in the centre; and also to the effect caused by closing the valve on the top of the descending gas-main, so that

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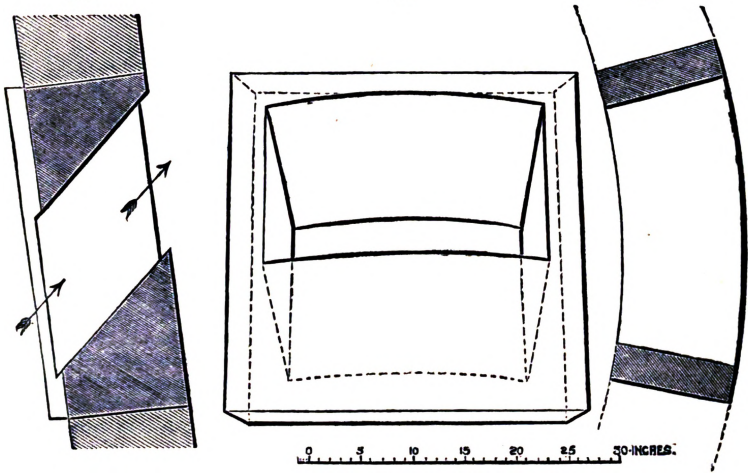


no gas or flame could then pass outwards through the openings, as there was no longer any current to draw the heat through the openings. Had a bell been at work in the centre of the furnace-top in this instance, the only way to save it would have been to disconnect it and lift it out entirely; but this could not have been done till the materials in the furnace-throat had lowered themselves below the mouth of the bell.

As the gas-openings are now cast, as shown in Figs. 729, 730, 731, it is anticipated they will stand for many years.

*Details of Blast Furnaces.*—Fig. 732 shows plan of hearth of blast furnace at Plymouth Iron Works. Fig. 733, plan of hearth of blast furnace at Rhymney Iron Works. Fig. 734, horizontal section through hearth at level of tuyeres, showing tuyeres and pipes in position, of large 18 ft. blast furnace, Dowlais Iron Works. Fig. 735 represents sectional plan of hearth of cupola furnace

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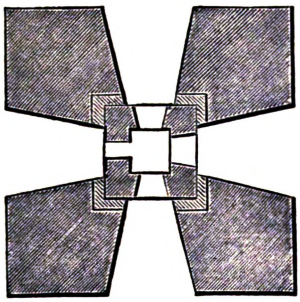

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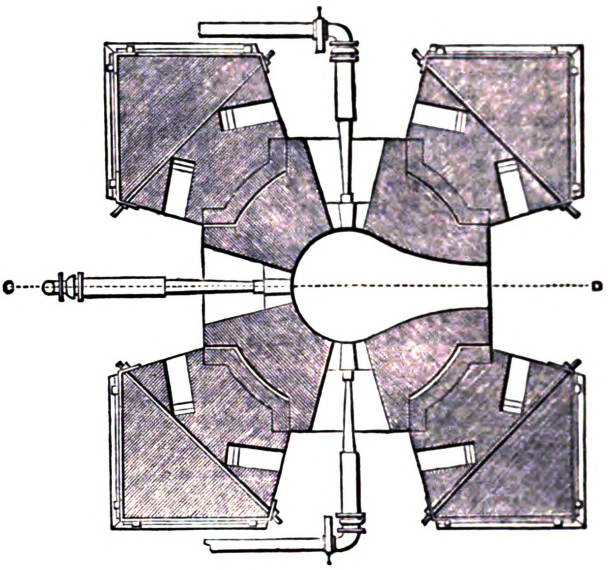

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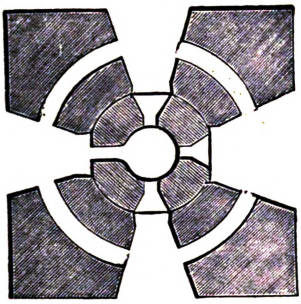

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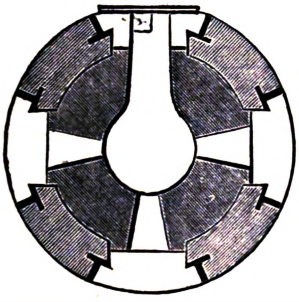

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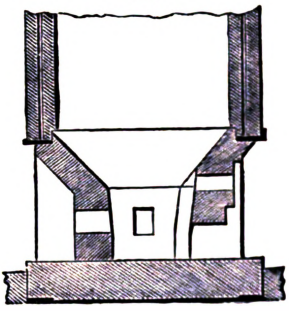

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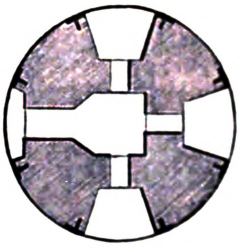

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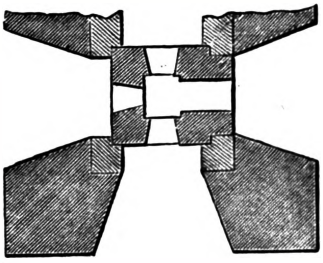

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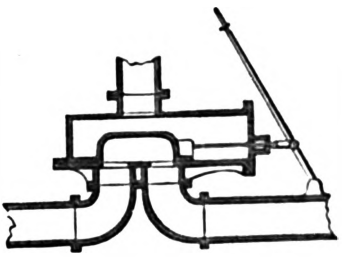

at Dowlais. Fig. 736 is a vertical section, and 737 plan of hearth of Aberamman furnace, showing tuyere-openings both in sides and breast; Fig. 738, plan of hearth of blast furnaces, Oldbury Iron Works; Fig. 739, section of valve-chest, with three passages, placed on blast-pipes of hot-blast furnaces, to direct the blast either through the stoves or at once into the furnaces at pleasure.

Figs. 740, 741, show a section and plan of a cinder-fall, in which is fixed a wrought-iron crane C; a cast-iron plate having its upper edge serrated to facilitate the removal of large masses of cinder; a cast-iron trough A, about 6 ft. long, to convey the fluid metal from the tapping-hole H, to the casting-bed or refinery B, B; two troughs *a a* are fixed on the cinder-bed, for guiding the fluid cinder into the tubs *t*.

Various plans for collecting furnace-gases are shown in Figs. 742 to 746. In Fig. 743, the cup, which is a funnel-shaped casting equal in its largest diameter to the throat of the furnace and 4 or 5 ft. deep, rests upon the top of the furnace by a flange round its outer edge. The orifice at the bottom measures from 3 to 5 ft. in diameter, and is closed by a conical casting, with the apex upwards. This casting is suspended by a chain from a lever which is counterbalanced at the other end. The materials are filled into the cup, and the workmen, by suitable gearing affixed to the lever, lower the cone, and the materials fall into the furnace, and the stopper is restored to its place by the counterpoise on the opposite end of the lever.

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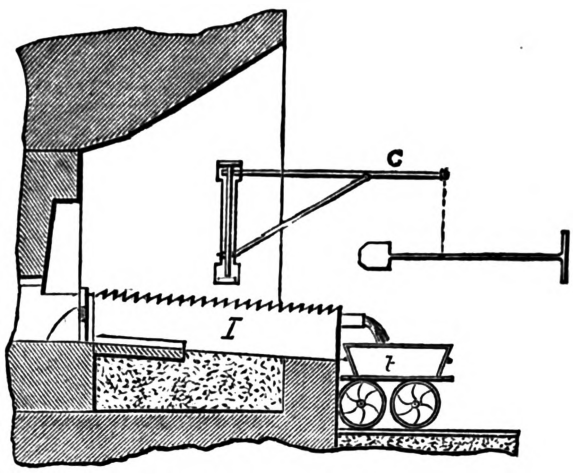


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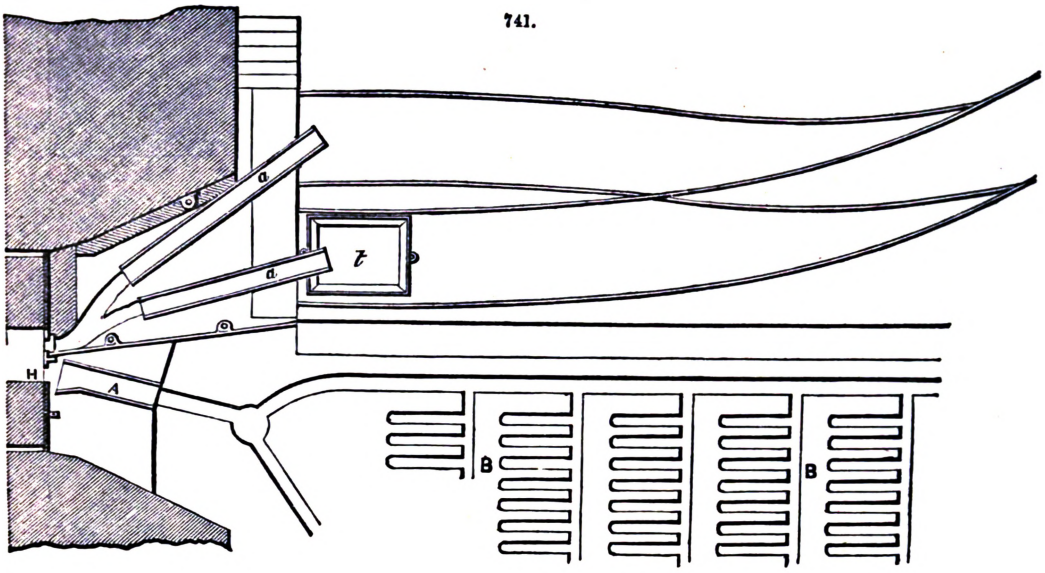


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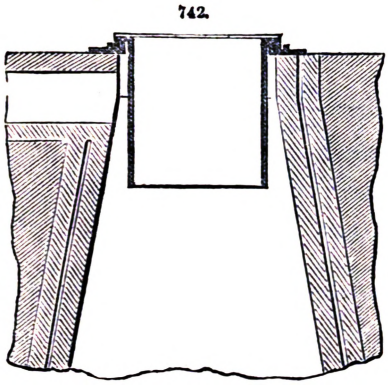

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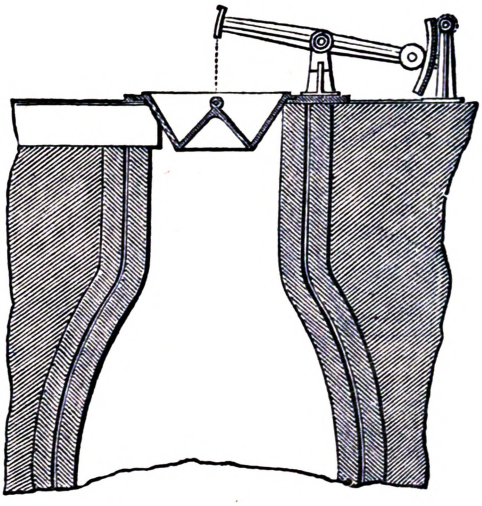

Another plan, Fig. 744, which has also been extensively adopted, consists of a lid fitting closely to the furnace: this lid is lifted by means of a counterbalance weight W, on each occasion of charging materials. No reduction in the working height of the furnace is caused by this arrangement, but the time during which the throat is open while the cover is being lifted, the materials filled in, and until it is again shut close, is very prejudicial to the quality of the gas. It is commonly stated, says Truran, that no gas passes while the cover is up; but this is an error: the same quantity of gas is evolved from the furnace whether the cover be open or closed; but if it is open, a large quantity of atmospheric air also passes into the pipes, increasing the bulk of the unprofitable gases, and thereby reducing the heating power of those that are combustible, as well as endangering the apparatus by causing a great increase of temperature in the pipes.

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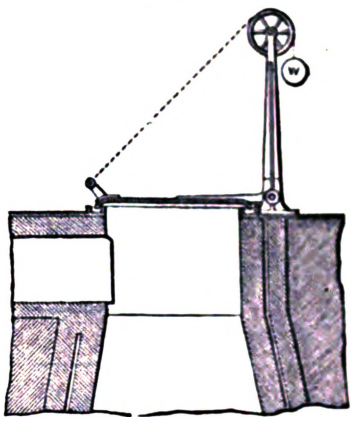
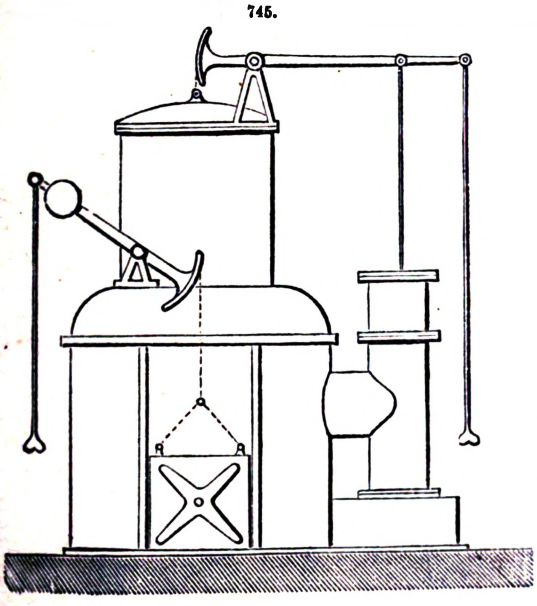



A third plan, Fig. 742, in use at some works is very readily applicable to existing furnaces (1862). An iron cylinder of 6 or 7 ft. in depth, and 6 or 8 in. smaller in diameter than the throat, is sunk into the furnace; a flange on the top, which rests upon the brickwork inside the tunnel-head, forms a joint and sustains the cylinder. The annular space between the cylinder and furnace underneath the flange and above the materials forms a chamber for the ascent of the gases, which are conveyed away through a suitable pipe or tunnel.

This plan also has its disadvantages. The duration of the cylinder is subject to great variation. In some cases it is burnt down in two or three weeks, and, under more favourable circumstances, seldom lasts longer than a few months. The cost of the cylinder, and the delay and expense attending its so frequent renewal, are formidable items in the working cost of this plan for collecting gas.

This method is also subject to the disadvantage of reducing the working height of the furnace. The cylinder, says Truran, is kept full of materials, it is true; but they receive very little heat while they are in it, as the hot gases are drawn into the outside flues, and do not enter the cylinders. It must be conceded that the capacity, and consequently the smelting power, of the furnace is diminished by the space occupied by the cylinder and chamber for collecting the gas. If the cylinder is immersed 7 ft., one-tenth of the capacity of the furnace will be useless so far as the reduction of metal is concerned. The deficiency of smelting power is still greater with the plan first described.

745.



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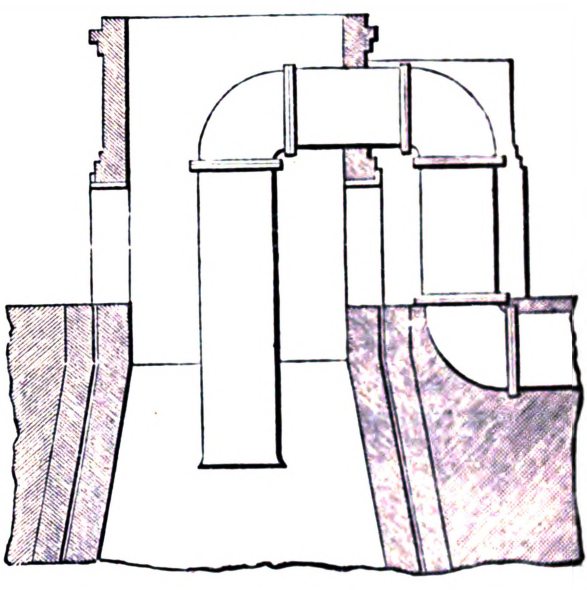
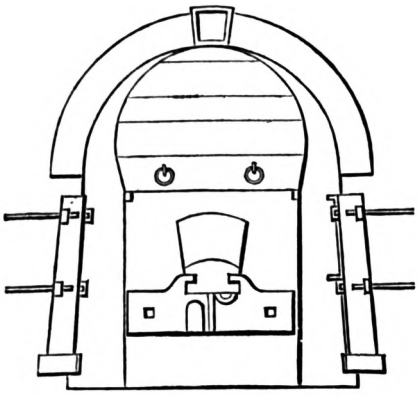


A fourth plan, Figs. 745, 746, of collecting the gases is considered by some engineers as the least objectionable. At a convenient depth, generally 8 or 10 ft. from the top of the furnace, an annular flue is constructed around the brick lining, with a number of orifices opening downwards into the body of the furnace. This plan leaves the form of the throat and the arrangements for filling unaltered. From the descending direction taken by the orifices communicating with the furnace, they are not liable to obstruction from the materials, and the supply of gas is probably more regular than with either of the other plans.

Fig. 747 shows a front view of a cinder-fall. A, B, C, Fig. 748, are moulders' tools. Figs. 749 to 753 show ordinary furnace-keepers' tools.

747.



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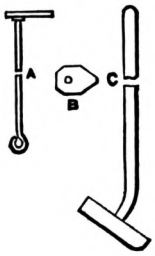


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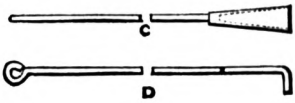


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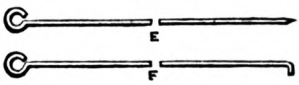


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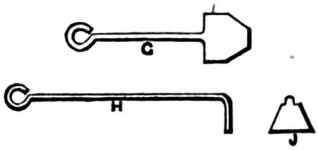


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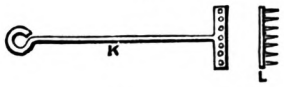


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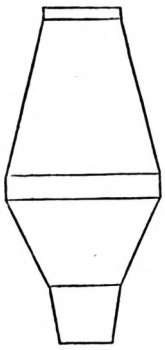

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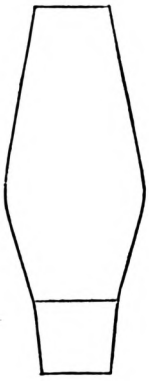

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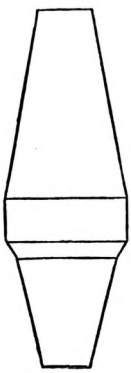

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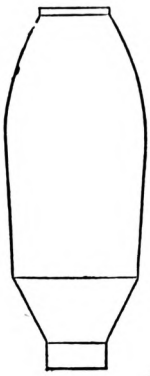

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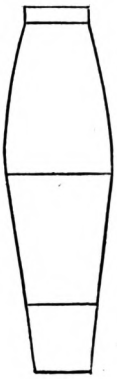

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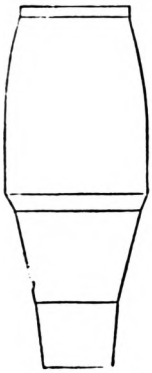

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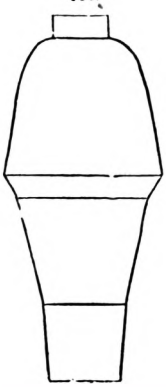

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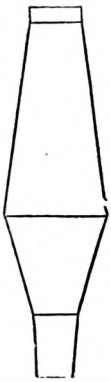

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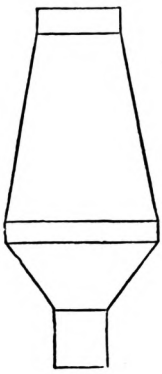

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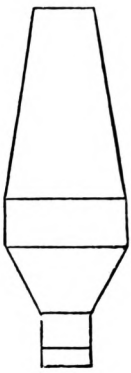
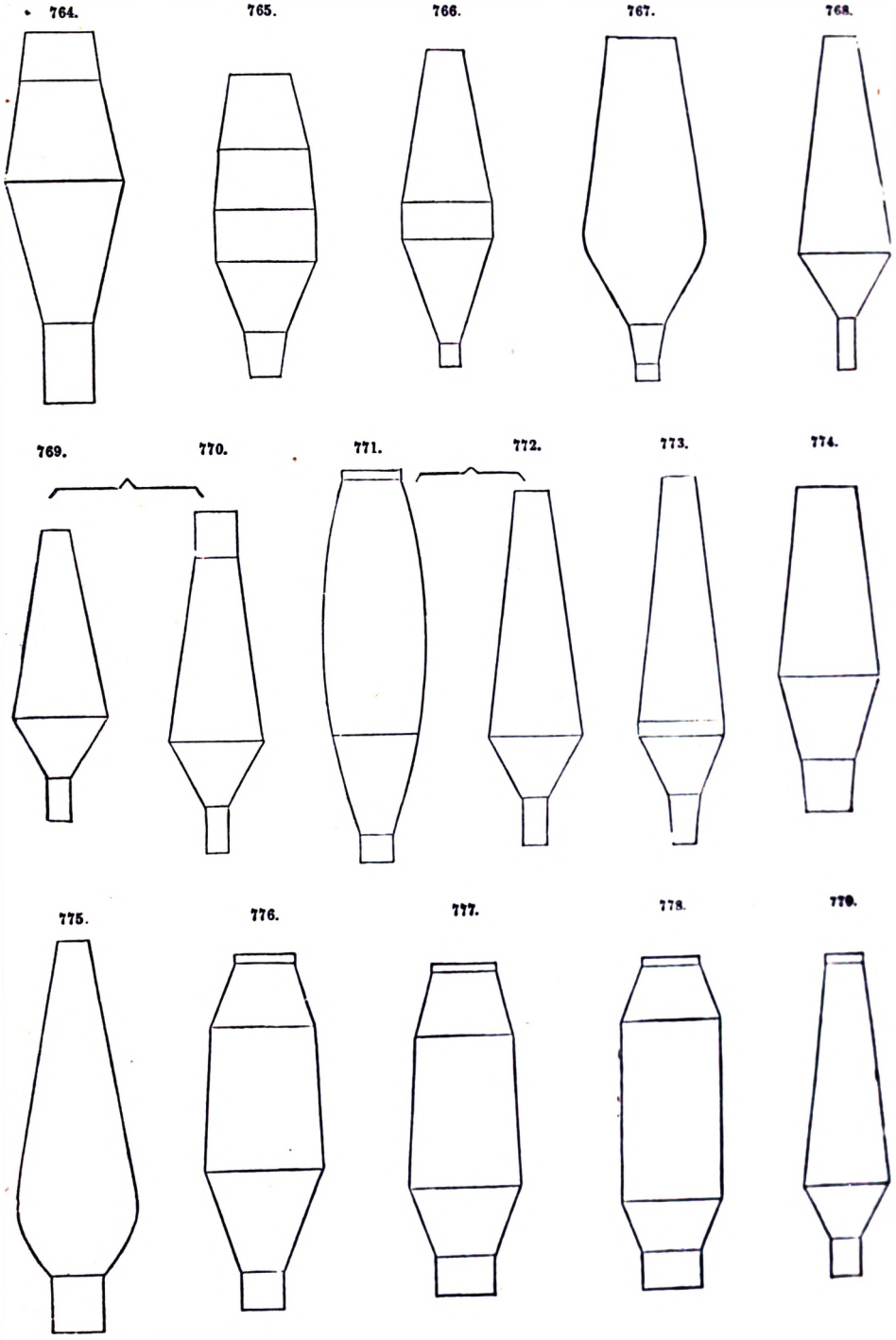
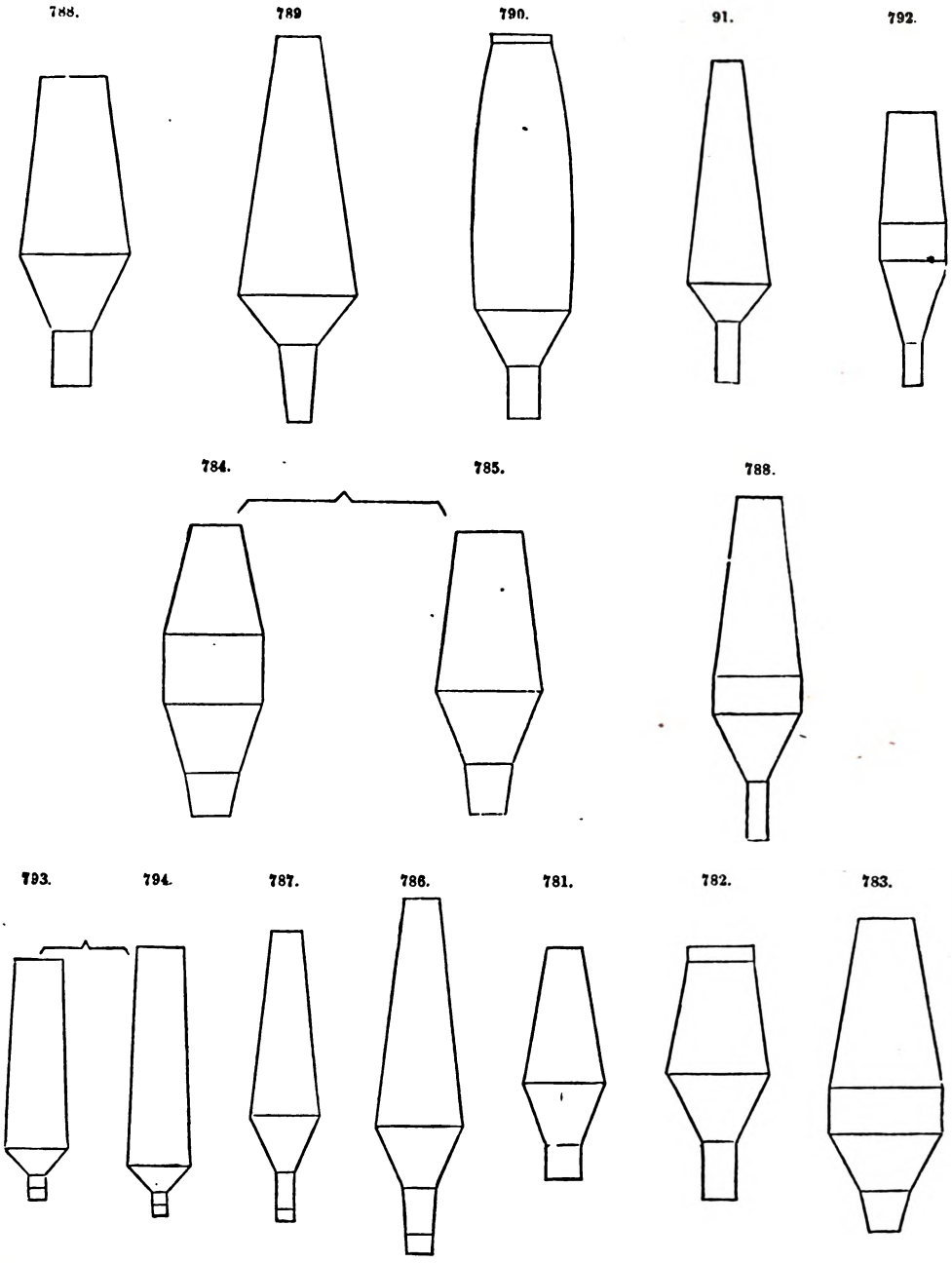


Outlines of blast-furnace interiors used at Rhymney are shown in Figs. 754, 755.

Fig. 756 shows the type adopted at Sirhowy; 757, Ebbw Vale; 758, 759, 760, 761, Dowlais Iron Works; 762, Hirwain; 763, Aberamman; 764, Pentyrch; 765, Landore; 766, Staffordshire; 767, Stafford; 768, Tipton; 769, 770, Shropshire; 771, 772, Corbyn's Hall; 773, Alfreton; 774, Wilkie; 775, Stockton; 776, Kinniel; 777, Dandyvan, 778, Muirkirk; 779, Ynisced wyn; 780 Ystalyfera New Furnace; 781, Ystalyfera Old Furnace, 782, Abernant; 786, 787, French; 783, 784, 785, American; 788, Silesian; 789, Norwegian; 790, Belgian; 791, Prussian; 792, Baermn; 793, 794, Hartz.

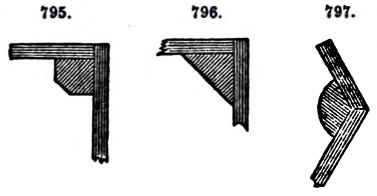
See Blowing Engines. Furnaces. Iron. Kilns. Ovens. Puddling and Puddling Machines. Rolling Mills. Squeezers. Steam-hammer. Steel. Tuyere.






BLAST-PIPE. Fr., *Tuyau de raréfaction*; Ger., *Zugrohr*; Ital., *Tubo di scarico.*
See Details of Engines.

BLIND AREA.—The same as an *Area-drain*, with the addition of cross-walls at intervals, usually built to assist the dwarf-wall in supporting the earth at its back. A blind area is inferior to an area-drain, as the cross-walls interfere with the circulation of the air.




BLINDING. Fr., *Gravier*; Ger., *Grobe Sand*; Ital., *Intasatura Insabbiamento.*
See Roads.

BLOCK. Fr., *Poulie*; Ger., *Block*; Ital., *Girella*; Span., *Polea.*
See Pulleys. Tackle.

BLOCK or BLOCKING. Fr., *Taquet*; Ger., *Eckleiste*; Ital., *Rinforzi.*

Small pieces of wood fitted and glued into the interior angles of two pieces of stuff to strengthen the joint. See Figs. 795 to 797.

**BLOCKHOUSE.** Fr., *Blockhaus*; Ger., *Blockhaus* Ital., *Ridotto Coperto*; Span., *Palanque*. See Fortification.

**BLOCKING-COURSE.** Fr., *Le dessus d'un corniche*; Ger., *Oberer Theil eines Karniess*; Ital., *Ultimi corsi*.

*Blocking-Course.* — In masonry, a course of stone placed on the top of a cornice.

**BLOOM.** Fr., *Loupe*; Ger., *Frischluppe*; Ital., *Massello*; Span., *Changote*.

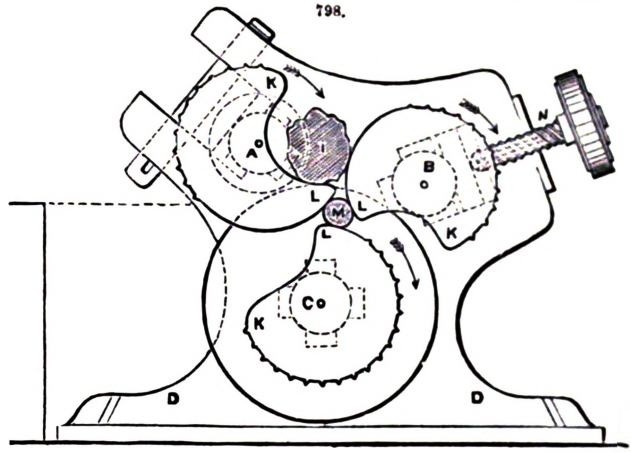
A mass of crude iron from the puddling furnace, while undergoing the first hammering previous to being rolled, is termed bloom.

**BLOOMING MACHINE.** Fr., *Machine à cingler*; Ger., *Presswerk Presse*; Ital., *Macchina da far i masselli*.

The blooming machine, invented by Jeremiah Brown, is shown in Figs. 798, 799, 800. It consists of three large eccentric rolls A B C, placed horizontally in the strong holsters D D, the centres of the rolls being arranged in a triangular position, and the bottom roll C being nearly central between the two top rolls A B. These rolls all rotate in the same direction, and are driven by a centre pinion E, working into three pinions of equal size F F F, fixed on the roll-spindles. In the present machine the driving power is applied direct to the bottom roll by means of the large wheel G, for the convenience of carrying the main shaft under the floor. The rolls are cast solid, with their journals like ordinary rolls, and are driven by coupling-boxes and spindles H H.

The roll-faces are 16 in. long, and the bottom roll has,

798.

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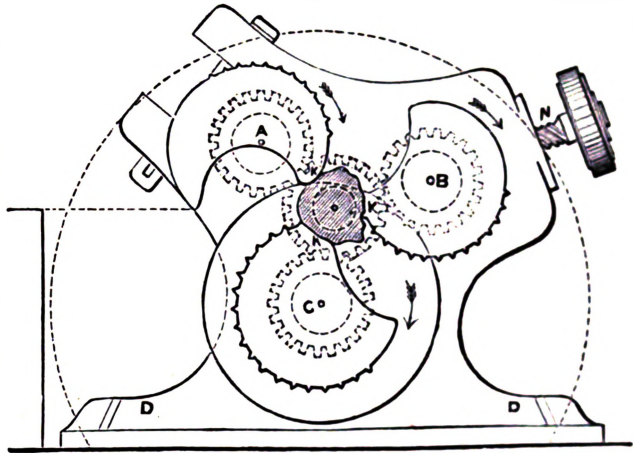


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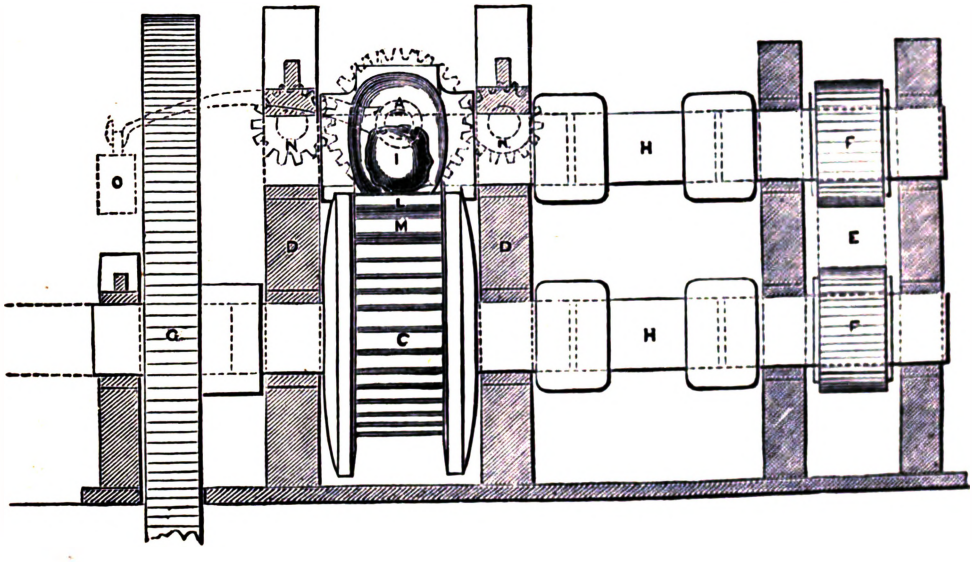


at each end, strong flanges, 8 in. deep, between which the two upper rolls work. The object of these flanges is to upset or compress the ends of the bloom, as the iron is elongated during the operation and the ends are forced against the flanges, which makes them square and sound. The top roll A has a large hollow in which the puddled ball I is placed by the puddler; this roll carries the ball round, and drops it into the space between the three rolls, as shown in Fig. 798, this space being at that moment at its largest capacity.

The three projecting points K K K of the rolls immediately impinge upon the ball, and compress it forcibly on three sides; and, giving a rotating motion to the ball at the same time, they have a powerful kneading action upon the iron, squeezing out the cinder, which falls down each side of the bottom roll. The space between the rolls gradually contracts, from the spiral or eccentric form of the rolls, and the iron is subjected to an increasing pressure, until it is liberated by the points L L L, simultaneously passing the bloom M, which falls in the direction of the arrow at the same moment that another ball is dropped in at the top of the machine. The projecting teeth on the surface of the rolls assist this action, by seizing the iron and kneading into it as it rotates; these teeth gradually diminish in projection, the last portion of each roll being plain, consequently the bloom is turned out in a smooth, compact form.

The space between the flanges of the bottom roll is widened for a short distance beyond the point L, for the purpose of allowing the bloom to fall out readily and admitting the fresh ball.

In order to prevent the rolls from being broken by any unusual size of ball, the machine is provided with two large triple-threaded screws N N, which bear upon the journals of one of the top rolls B; a small pinion on the head of each of these screws works into a large pinion fixed between them, which has a horizontal lever fixed to it, carrying a balance-weight O at the end. This weight causes a constant equal pressure of the roll, and, if a ball of extra size be put into the machine, the screws yield by turning back and lifting the weight to the extent required, so that a large ball may be worked in the same manner as those of smaller sizes.

A continual stream of water runs on to all the journals in the machine, thus preventing them from heating while the machine is at work.

BLOWING ENGINE. Fr., *Soufflerie*, Ger., *Gebläse*; Ital., *Macchina soffiante*; Span., *Bofeton*. See Engines, *Varieties of*.

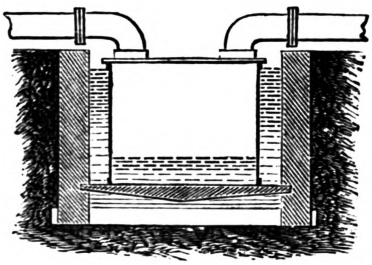
BLOWING MACHINE. Fr., *Machine soufflante*, Ger., *Gebläse Maschine*; Ital., *Macchina soffiante*; Span., *Bofeton*.

A blowing machine is a machine or engine for forcing a strong and continuous blast of air into a furnace.

The first records show blowing cylinders to have been single-acting, that is, having the power of propelling the blast when the piston was moving in one direction only. Two or more of these blowing cylinders appear to have been attached to one crank-shaft, worked by a water-wheel, and thus a tolerably steady pressure of air was obtained. When the gradual improvements of the steam-engine and the demand for increased means of manufacture caused it almost entirely to supersede all other power, blowing apparatus appears to have been accommodated as much as possible to the steam-engine, so as to afford the character of engine for the time being the fullest development of its power.

In pursuance of this object, the single-acting atmospheric engine of Newcomen was attached to a blowing cylinder, which propelled the air from the upper side of the piston only; and in addition

801.



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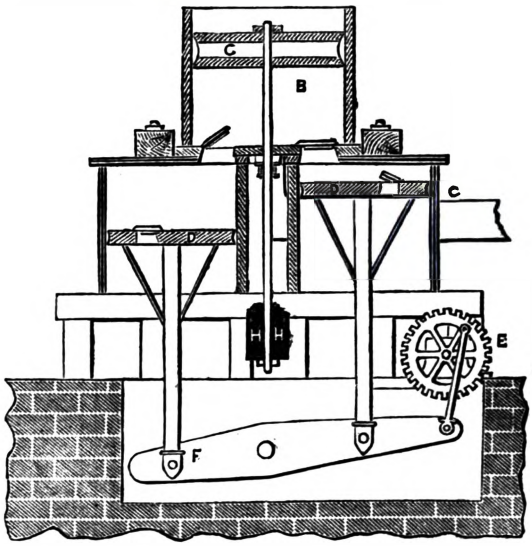



to the water-regulator, Fig. 801, which appears to have been known at an earlier date, there was attached a cylinder, B, Fig. 802, now known as the regulating tub, which was equal to or larger in diameter than the blowing cylinder. In this was fitted a piston G, with a rod moving in a guide fixed on the open top of the regulating tub, the bottom of the latter being close, and having an open connection to the main from the blowing cylinder. The piston in the tub was loaded at H to the pressure of blast required, and in the intervals between the discharges of the blowing cylinder, the descent of the piston in the tub kept up the discharge of air into the water-regulator, which intervened between it and the furnace; thus in effect, as far as possible, making the engine double-acting. To prevent the piston being blown out of the regulating tub, a large safety-valve was attached to the top of

the rod by a strap, long enough to allow the desired play of the piston, and short enough to lift the safety-valve, or snorter, as it is usually termed, if the piston at any time exceeded its limits; and the number of strokes of the engine was also regulated by the tub-piston, as to it the cataracts were attached.

When the double-acting engines of Watt were introduced, the regulating tub was still retained, though not nearly so essential a part of the machine as in the former instance.

The next change that took place was the general abandonment of the water-regulator, though some of these are still at work, or have been within a few years. The reason for this change was the discovery that the air in summer, already surcharged with moisture, took up an additional quantity from passing over the surface of the water in the regulator, and that this was prejudicial to the working of the furnaces.

When the large area of the water-regulator was shut off, it was then found that the tub was by no means such a perfect regulator as it was supposed to be, as the momentum of the engine passed too suddenly into the heavy piston of the tub, and, throwing it up much beyond the height due to the pressure of the air, caused an irregularity that was even more aggravated by its descent. To counteract this, a spring-beam was placed on the top of the tub, so as gradually to check the momentum of the piston; and this had some effect, but not at all a satisfactory one.

The next alteration which appears to have suggested itself, was the application of large *air-chambers*, from twelve times to thirty times the area of the blowing cylinder, in which the elasticity of the compressed air acted as the regulator of the discharge; the tub, with its piston, being in some cases retained to work the cataracts, and as a tell-tale against the engine-men in case of their allowing the steam to slacken and the piston to descend. In other cases the tub was dispensed with altogether.

We now enter upon the last change which took place some thirty years ago, namely, the coupling of two double-acting engines and double-acting blowing cylinders upon the same crank-shaft at right angles, so as to keep up a regular discharge. This effect was in some measure obtained; but an air-chamber, or what is equivalent to it, very large mains, was still required to obtain a satisfactory result.

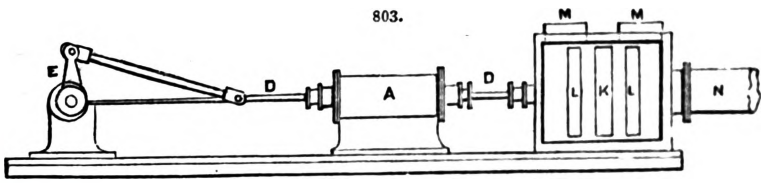
At this point the realized improvements of the blowing engine stop short, leaving it still a large, cumbrous, and expensive machine, and not capable of moving through its valves the HIGHLY ELASTIC MEDIUM AIR at a greater rate than the absolutely NON-ELASTIC FLUID WATER is moved through an ordinary pump. Under these circumstances it must be obvious that, after all the engineering talent that has been spent on this description of engine, there is still (if the expression may be applied) a wide range of discovery open.

The immediate cause of my attention being attracted to the improvement of the blowing engine, says Archibald Slate (to whose paper, read before the Inst. of Mechanical Engineers, we are indebted for the present article), was the difficulty experienced in regulating one of the old construction of blowing engine in the latter part of 1848, having at the same time occasion to employ some small 9-in. cylinders driven by the air of the large blowing engine. These small cylinders, when driving the shafting only, sometimes attained a velocity of upwards of 200 revolutions a minute, suggesting the idea of the possibility of reversing their motion, and taking in the air in place of blowing it out through them; there was, however, a difficulty in the slide-valve, which did not open and shut fast enough. After some consideration, it was agreed that another cylinder should be prepared, the centre-port made much larger, and the slide over-travelled nearly half its stroke in excess, which had the desired effect; a cylinder of 9 in. diameter, and 1 ft. stroke, having been driven 320 revolutions or 640 ft. a minute, discharging the air, at a pressure of 3½ lbs. the square inch, through a tuyere of 1⅛ in. diameter, or $\frac{1}{64}$th of the area of the blowing piston. This performance was in 1850 more than double that of any ordinary engine, the total area of the tuyeres with a 90-in. blowing cylinder being, at a pressure of 3½ lbs., about 52 circular in., or $\frac{1}{144}$th of the area of blowing piston.

We are all acquainted with the tremor which is felt even in the best form of the large-sized engines; but in the experiments at a high velocity with the small-sized cylinders, not the slightest jar was felt or noise heard; it was therefore proposed to increase the speed of the piston in actual practice, from 640 to 750 ft. a minute, the length of stroke being 2 ft. in place of 1 ft.; this is somewhat under the speed of a locomotive piston at 40 miles an hour, which is about 800 ft. a minute, so that it was conceived no difficulty could present itself to this. The proposed speed of 750 ft. a minute was three times the usual speed of the blowing engines then in use (250 ft. a minute).

The construction of the engine proposed by A. Slate is shown in the accompanying drawings. Fig. 804 is a plan, and Fig. 803 an elevation of the engine, showing the pair of steam-cylinders and

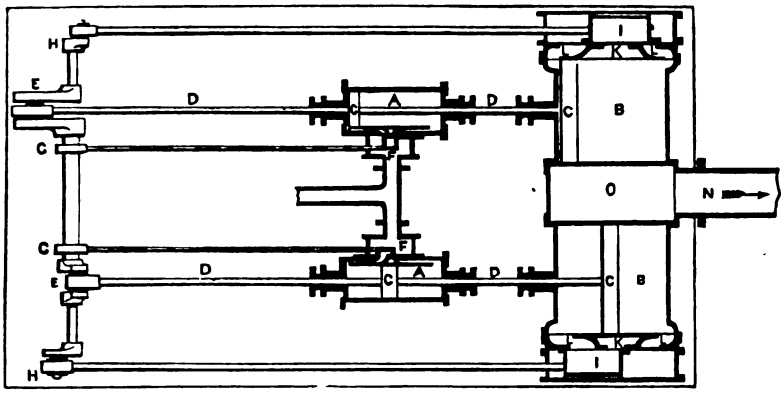
803.




blowing cylinders; A A are the steam-cylinders, 10 in. diameter and 2 ft. stroke; B B blowing cylinders, 30 in. diameter and 2 ft. stroke, with their pistons C, fixed on the same piston-rods D, which are connected to two cranks E, fixed at right angles to each other on the same shaft. The slide-valves F of the steam-cylinders are worked by the eccentrics G on the cranked shaft, and the cranks H, at the outer ends of the same shaft, work the slide-valves I of the blowing cylinders. The centre-port K passes downwards to an external opening for the admission of the air, and the

discharge-ports L L deliver into the passages M on the top of the cylinder, which communicate with the air-main N by the chest O formed between the cylinders. The piston of the blowing cylinder is intended to be made without any packing, being a light hollow cast-iron piston turned to an easy fit; and the slide-valve of the blowing cylinder to have a packing-plate at the back, working against the cover of the valve-box, with a ring of india-rubber inserted between this plate and the back of the valve, to give a little elasticity.

804.




It appears that 30 in. diameter is about the most convenient size for a stroke of 2 ft.; and as it is considered an advantage to have the stroke as short as possible, to increase the regularity of the blast, the comparative cost of the different engines which follow has been taken upon this basis, $\frac{2}{10}$-in. steam-cylinders and $\frac{2}{30}$-in. blowing cylinders being reckoned equal to blow one of our largest furnaces, making 160 tons of iron a week, and having a surplus equal to blowing a cupola or refinery, as it is generally allowed that such an engine would give at 640 ft. a minute the same speed of piston as in the experiments, very nearly 30 circular in. of tuyere, at a pressure of $3\frac{1}{2}$ lbs. to the sq. in. The circular inch is used in speaking of the area of tuyere, as the blast that any furnace is taking is usually reckoned by simply squaring the diameter of the tuyere, but the pressure is taken on the square inch.

The experiments on which these calculations were founded, having been made in 1849, were repeated in 1850, and the results were found to be, as nearly as they could be measured, the same; the blowing cylinder had in the interval been driving the lathes in the pattern-shop, and the slide was found perfect. An indicator was applied with a view to test the amount of friction of the air in entering the cylinder at the high velocity, and a simple method was adopted of ascertaining this. A tuyere was made as large as the inlet-port, and the engine was driven to nearly or quite 700 ft. a minute, when the gauge showed a pressure of $\frac{1}{4}$ of a lb. to the square in., and as the friction would be the same through the same sized openings at other pressures, it follows that the loss by friction, on a pressure of blast of $3\frac{1}{2}$ lbs. the inch, would be $\frac{1}{15}$th or $6\frac{2}{3}$ per cent. loss; as the port in this case was $\frac{1}{11}$th of the area, and the port proposed is $\frac{1}{8}$th, it is assumed that the loss would not exceed 5 per cent. from this cause, or indeed from any other cause, as the friction from propelling the air through a given sized tuyere, at a given pressure, must be the same in both cases.

We extract a description of a set of six blast-engines, made for the East Indian Iron Company, from a paper by Edward A. Cowper, read before the Institute of Mechanical Engineers in 1855.

These engines were made to the plans and under the superintendence of Charles May, the consulting engineer to the East Indian Iron Company, by James Watt and Co., to the drawings prepared by E. A. Cowper.

The engines are six in number, two pairs of them being intended to blow air at 2 lbs. the square in. as a maximum pressure, and the other pair to blow air at 4 lbs. the square in. as a maximum pressure.

Fig. 805 is a side elevation of the engine complete, with crank-shaft, wheels, and other fittings.

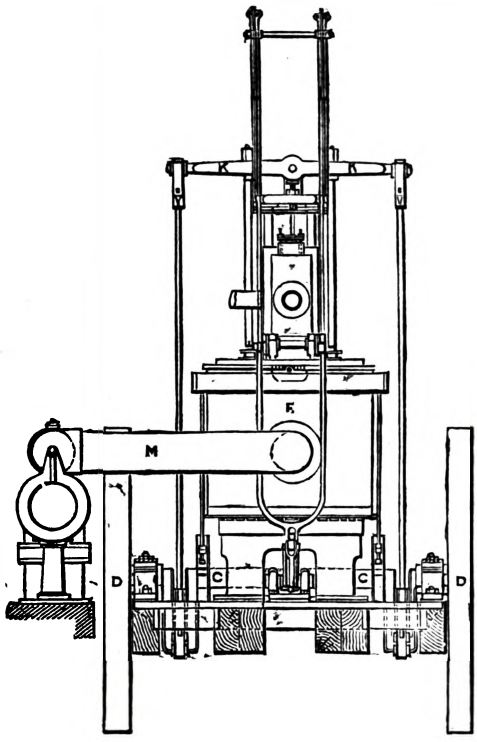
Fig. 806 is a vertical section through the steam and air cylinders, and their valves and passages, and the branch air-pipes.

Fig. 807 shows a sectional plan taken through the air-valve, and the air-passages and branch air-pipes.

The general form and construction of the engine is that of a Pedestal or Table Engine; the air-cylinder A stands on a short pedestal, and itself forms the pedestal or table on which the steam-cylinder B stands. The foundation-plate is 6 ft. square, and carries a wrought-iron crank-shaft C in four plummer-blocks, having two light fly-wheels D D, one on each end of the shaft, and the two eccentrics E E for driving the air-valve F, one on each side of the air-cylinder, and the eccentric G for driving the steam-valve H, in the centre. The steam-piston has one piston-rod fixed in a short cross-head I at the top, and this cross-head has two other piston-rods, for driving the air-piston, which pass down outside the steam-cylinder through stuffing-boxes in the cover of the air-cylinder, and are attached to the air-piston. The long cross-head K, taking the connecting-rods to the cranks, is attached to the short cross-head by a pin, so as to allow a little freedom in case of unequal wear; the guides L L are attached to the steam-cylinder cover. V is section of air-valve.

The air-valve F is made under Archibald Slate's patent. It consists of a ring or crown valve entirely enclosing the air-cylinder, and is not self-acting by the pressure of the air in any way, but is moved by the pair of eccentrics E E at the proper times, so as to give ample passage for the air

805.

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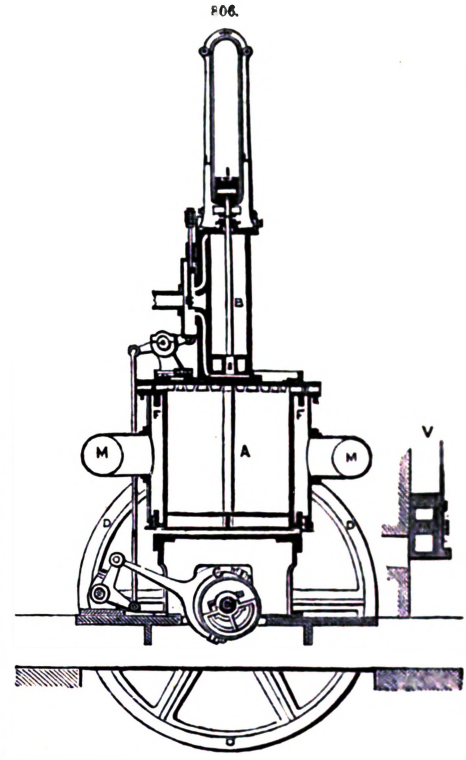
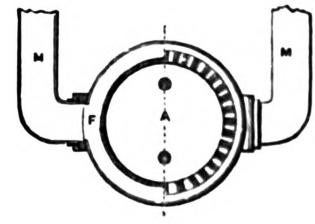



to move with the greatest freedom, and the valve has such a proportion of lap as to cause the air to be compressed up to the working pressure before it is delivered, thus giving the engine no more work to do than is necessary.

807.




The openings or passages for the air from the air-cylinder to the valve are extremely short, and the bars between the openings are made inclined, so as to cause a regular wear on the brass packing-rings which form the rubbing-face of the valve. The body of the air-valve is made of thin sheet iron, neatly curved to two turned cast-iron rings, to which it is well secured by a great number of small bolts. These rings are bored out inside to receive the brass packing-rings before mentioned, which are secured in their places by bolts. There are no springs to the brass packing-rings, but they are bored out to a perfect fit to the outside of the air-cylinder, and are then cut into eight pieces, and, should any wear take place, they can be at once adjusted by introducing a thin sheet of paper behind them and screwing them fast in their places again. It should, however, be remarked that this valve is under totally different circumstances from any that have hitherto been made, as it is perfectly in balance, or rather it is suspended freely, slides up and down a turned cylindrical surface, and therefore there is no tendency or power to cause wear under any variation in the pressure of the air. The mode in which the two eccentrics drive the air-valve is by means of a Gymbal Ring; that is to say, there is a wrought-iron ring encircling the air-valve and attached to it by two pins opposite each other, and the eccentric rods are attached to the ring at two other points at right angles with the first: thus the air-valve is perfectly free.

The air-cylinder A is 30 in. diameter and 2 ft. 6 in. stroke, and the piston makes 80 strokes a minute. The air-piston is packed with hemp-packing, and has a ring to screw it down; the screws are so arranged that they can be got at by simply unscrewing small plugs in the cylinder-cover, when a socket-spanner can be introduced to screw the ring down. The air passes into the air-cylinder beyond the end of the valve, first at one end and then at the other, and is delivered into the hollow part of the valve, from which it escapes through two light copper branch-pipes M M, placed opposite each other, and having turned joints fitting turned collars fixed on the valve. The other ends of the pipes rest on a small surface or shelf prepared for them, and on which they slide backwards and forwards about $\frac{1}{8}$th in. These ends of the pipes are curved in the same manner as the other ends, so that the faces are in one plane, and the air-main, Fig. 805, has the faces of its branches surfaced to receive them; thus the air is taken equally from each side of the air-valve.

The steam-valve H has considerable lap, and is so proportioned as to cut off the steam just after the half-stroke and have a very free exhaust.

The boilers are on the Cornish plan, and will be chiefly used with wood as fuel, and the furnaces are made proportionately large for this purpose. The boilers are fed by a donkey engine entirely independent of the blast engine, so that they are complete in themselves, and there is no fear of getting short of water whilst the blast engines stand for tapping, at which time indeed the boiler should always be fed, if only to keep the steam down a little.

The engines having to be transported some distance up the country, a limit of weight was given, namely, 1 ton for any one part of the engine; and in accordance with this limitation the total weight of a pair of these engines is only 11 tons as compared with 25 tons, the weight of an ordinary blast engine of equal power; and the weight of the heaviest single piece of an ordinary engine is 4½ tons as compared with 1 ton, the weight of the heaviest piece in the new engines. It is, therefore, evident that the engine can be moved with the greatest facility; and the first pair put to work here for trial simply stood on some *balks* of timber, and a few small bolts through the bed-plates were sufficient to hold them and cause them to work quite steadily; whereas for the ordinary engine a strong building with massive foundations has to be erected.

The method by which a high speed for blast engines has been attained is simply that of moving the air-valves for the air, having of course very large valves and passages, instead of letting the air itself move the valves. This arrangement at once prevents all blow and jar in the working, provided that the lap and lead of the valve are properly proportioned, and allows of the piston being driven at a high velocity, and consequently its diameter may be reduced and its stroke shortened. This mode of working, combined with the fact of two engines working together as a pair with their cranks at right angles, causes such uniformity in the flow of the blast that no regulator of any kind is needed; indeed, the variation is hardly perceptible in a mercury gauge placed on a very short length of main, whereas the variation on the ordinary plan is very considerable. The pair of engines are arranged to blow 3600 cub. ft. a minute, and are speeded to 80 revolutions a minute, which with 2 ft. 6 in. stroke makes 400 ft. a minute, and this they do with the greatest ease and efficiency, owing to the exact manner in which the lap, lead, and area of passages, &c., are proportioned.

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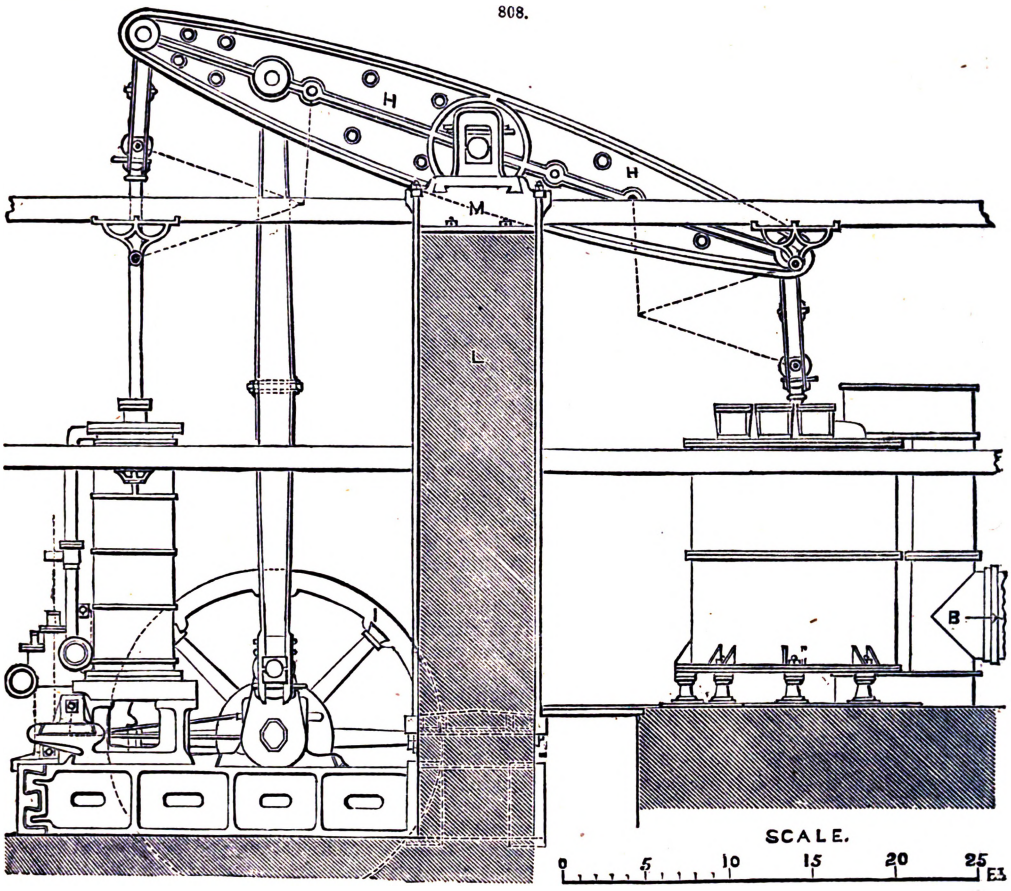


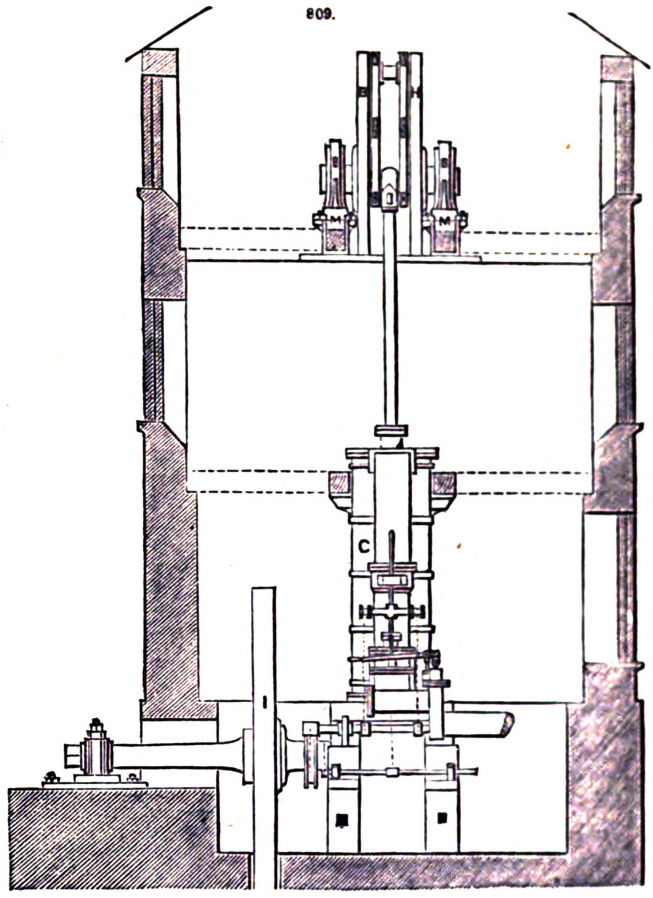

The following account of the blowing engine in use at the Dowlais Iron Works, is taken from a paper in the 'Transactions of the Institute of Mechanical Engineers,' read by Wm. Menelaus.

The blowing engine was erected in 1851, and is shown in Figs. 808 to 811. Fig. 808 is a side elevation of the engine, and Fig. 809 an end elevation. Fig. 810 is an enlarged vertical section

of the blowing cylinder. Fig. 811 is a vertical section of steam-valves. The blowing cylinder is 144 in. in diameter, with a stroke of 12 ft., making 20 double strokes a minute, the pressure of the blast being 3¼ lbs. the square in. The discharge-pipe B is 5 ft. diameter, and about 140 yds. long, thus answering the purpose of a regulator. The area of the entrance air-valves is 56 sq. ft., and of the delivery air-valves 16 sq. ft. The quantity of air discharged at the above pressure is about 44,000 cub. ft. a minute.

The steam-cylinder C is 55 in. diameter, and has a stroke of 13 ft., with a steam-pressure of 60 lbs. the square in., and working up to 650 horse-power. The steam is cut off when the piston has made about one-third of its stroke, by means of a common gridiron-valve A near the back of the slide-valve E, as shown enlarged in Fig. 811; there is also on one side of the nozzle a small separate slide-valve B, for moving the engine by hand when starting. The cylinder-ports are 24 in. wide by 5 in. long, and the slide-valve E has a stroke of 11 in. with ½-in. lap. The engine

809.

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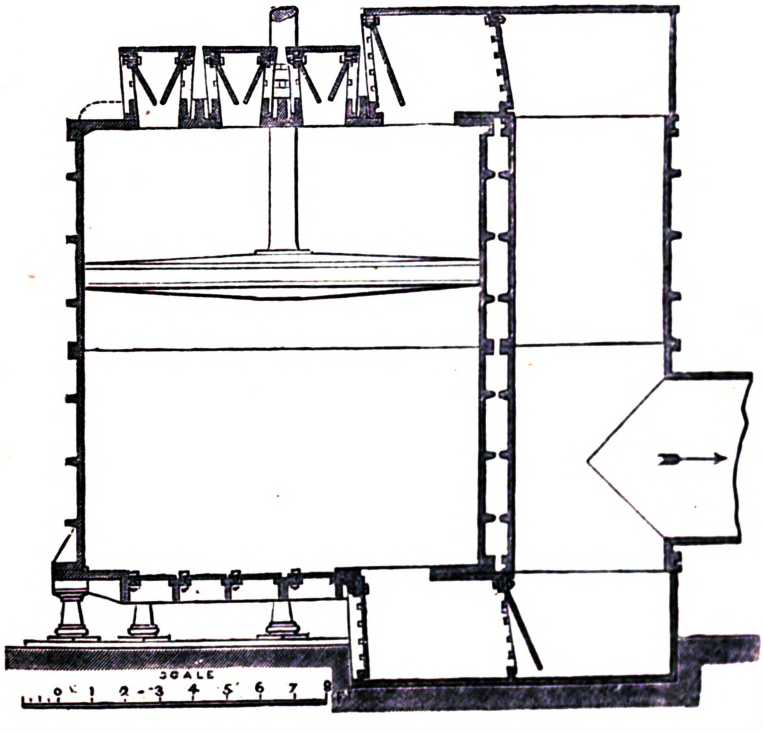
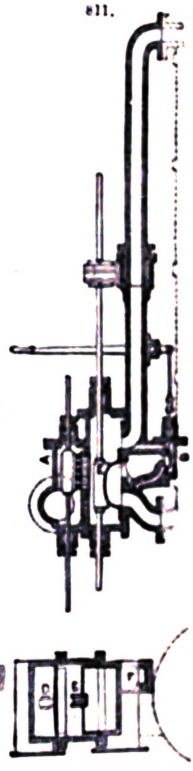



811.



is non-condensing, and the steam is discharged into a cylindrical heating tank 7 ft. diameter and 36 ft. long, containing the feed-water from which the boilers are supplied. Under the steam-cylinder C there are about 75 tons of cast-iron framing, and 10,000 cub. ft. of limestone walling in large blocks, some of them weighing several tons each.

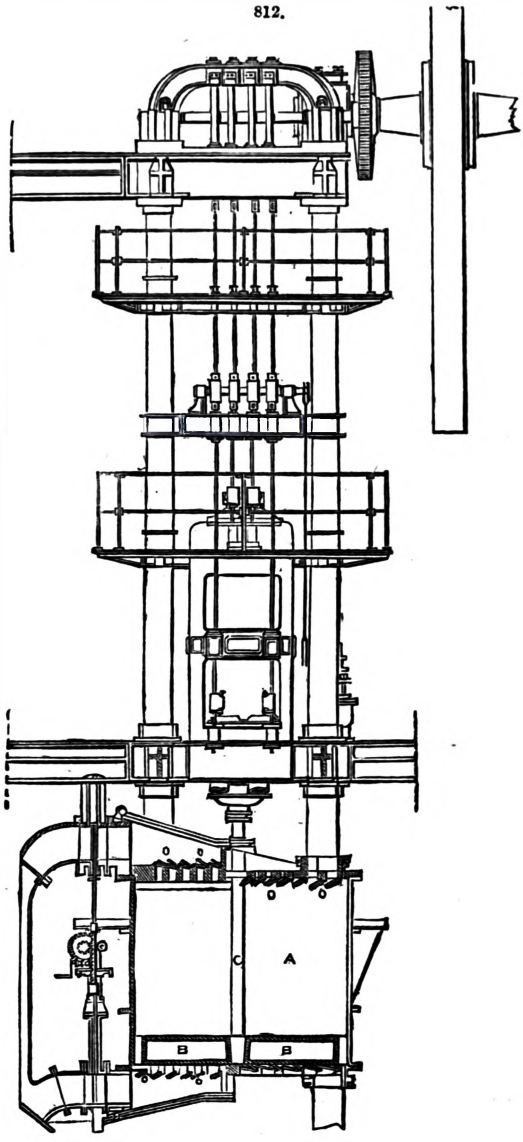
The beam H is cast in two parts, of about 16½ tons each, the total weight upon the beam-gudgeons being 44 tons; it is 40 ft. 1 in. long. from outside centre to outside centre, and is connected to the crank on the fly-wheel shaft I by an oak connecting-rod, strengthened from end to end by wrought-iron straps. The beam is supported by a wall L across the house, 7 ft. thick, built of dressed limestone blocks, to which the pedestals M are fastened down by twelve screw-bolts of 3 in. diameter. The fly-wheel I is 22 ft. diameter, and weighs about 35 tons.

Eight Cornish boilers are employed to supply the steam, each 42 ft. long and 7 ft. diameter, made of $\frac{9}{16}$-in. best Staffordshire plates, and having from end to end a single 4-ft. tube, in which is the fire-grate, 9 ft. long.

For some time this engine supplied blast to eight *furnaces* of large size, varying from 16 to 18 ft. across the *boshes*; it is now blowing, with three other engines of small dimensions, twelve furnaces, some of which make upwards of 235 tons of good forge pig-iron a week, the weekly make of the twelve furnaces being about 2000 tons of forge pig-iron. With the exception of the cylinders, made and fitted at the Perran Foundry, Truro, this engine and boilers were made at the Dowlais Iron Works, and erected according to the design and under the superintendence of Samuel Truran, the Company's engineer.

*Blowing Engines at Creusot.* — Schneider and Co's. works at Creusot include amongst their plant seven blowing engines, three of these being horizontal engines of an old type, and the other four direct-acting vertical engines; one of these latter is shown in Fig. 812. It will be seen that the blowing cylinder A, which is 108¼ in. in diameter, is placed below the floor of the engine-house, the steam-cylinder, which is 47¼ in. diameter, being overhead. The two pistons B B are fixed on one rod, and their stroke is 6 ft. 6¾ in. The piston-rod C passes through the top of the steam-cylinder, and is attached at its upper end to a cross-head working in suitable guides. From the cross-head a *connecting-rod* extends to the *crank-shaft*, the centre of the latter being 25 ft. 10½ in. above the floor of the engine-room, and no less than 44 ft. 3½ in. above the base of the engine.

812.

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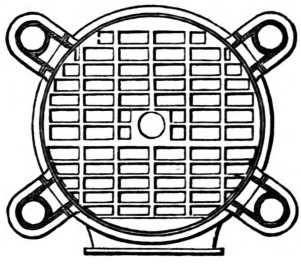

The admission of the steam to, and its release from, the cylinder are effected by equilibrium-*valves* worked by *cams* placed on a counter-shaft, which derives its motion from the crank-shaft through spur-*gearing*. The engine is of the non-condensing class, and the steam, which is supplied at a pressure of 60 lbs. the sq. in., is cut off at one-fourth of the stroke. The speed is usually 15 revolutions a minute.

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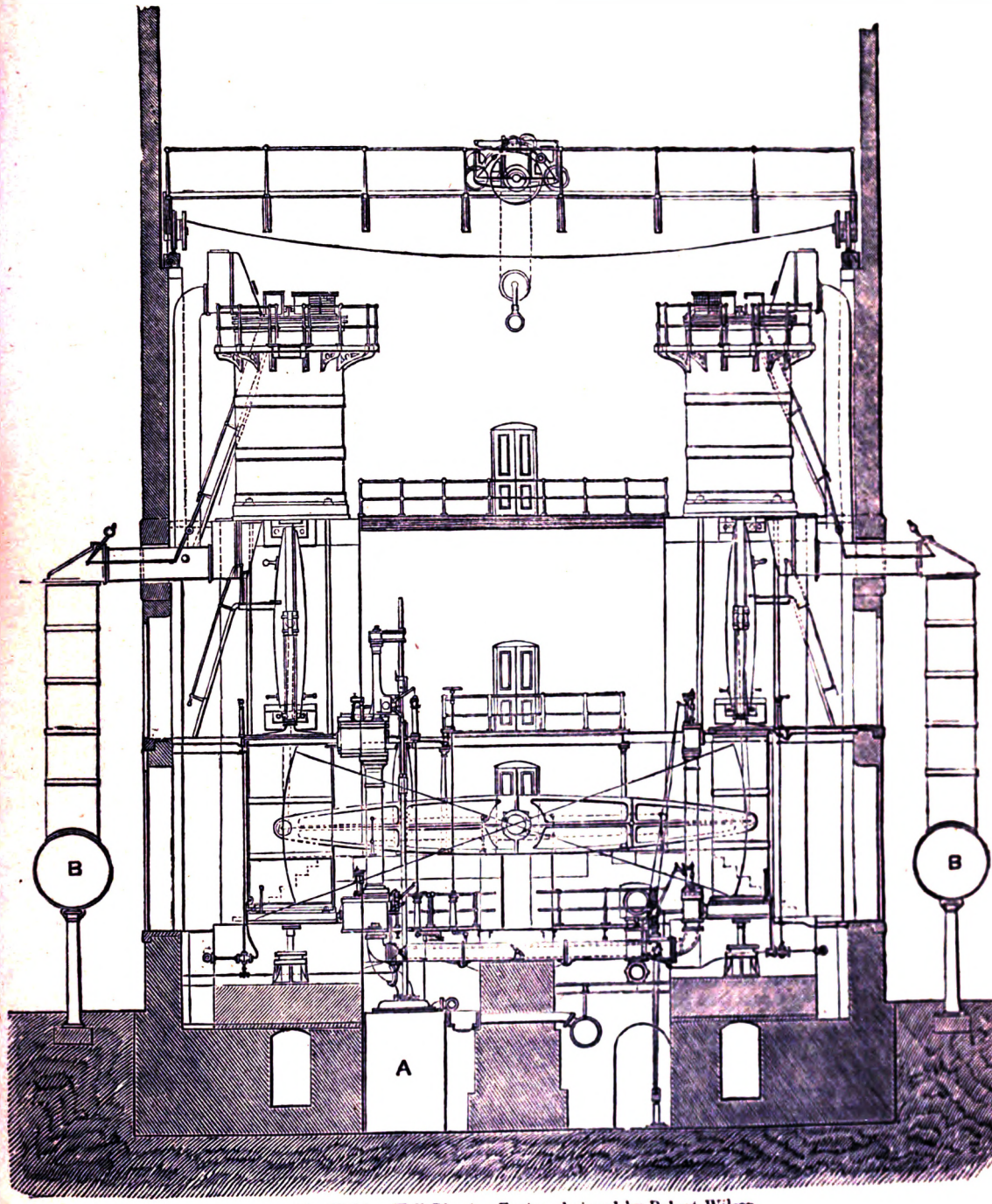



The Kirkless Hall Blowing Engine, designed by Robert Wilson.

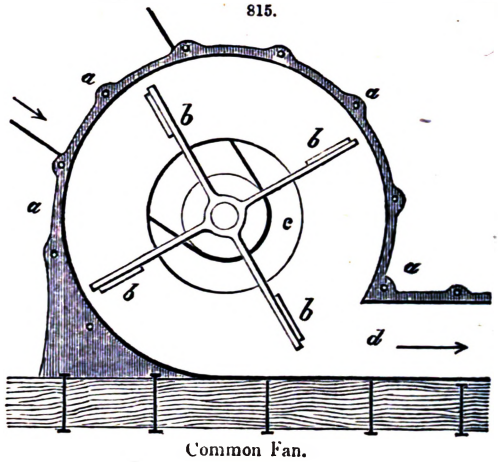
The blowing cylinder is fitted with a number of small flap-valves, O, O, arranged on each cover, as shown by Figs. 812, 813. One-half of each cover, it will be noticed, is devoted to the inlet, and the other half to the delivery valves. The blast is delivered at a pressure of 6¼ in. of mercury, or rather more than 3 lbs the sq. in., and the quantity delivered is 90 per cent. of that due to the capacity of the blowing cylinder. The four engines, which are appropriately named the Simoun, Sirocco, Mistral, and Ouragan, are placed in one engine-house, and they serve to supply blast to twelve blast furnaces.

*The Kirkless Hall Blowing Engines.*—These fine engines were constructed by Naysmith, Wilson Company, from the designs of Robert Wilson, for the Wigan Iron and Coal Company. Their whole arrangement is shown in Fig. 814. The engine-house is a handsome detached structure about 25 yds. long., 60 ft. wide, and 72 ft. high, and is entered by means of a large square tower, having an internal spiral staircase, with doors communicating with the several galleries in the engine-house. On the top of this tower is placed a balcony, from which an extensive view of the surrounding country is obtained. The interior of this tower is entered by a flight of stone steps. The first impression on entering the engine-house is one of complete astonishment, there being little of the ordinary appearance of an engine-house to be seen. There are two handsome iron galleries extending round the whole of the interior; some feet below the first are seen the immense engine-beams, each beam being about 38 ft. long, and weighing upwards of 20 tons. These beams, notwithstanding their enormous size and weight, move as easily and gently as if they were the merest toys, and this without the usual control of a fly-wheel, which, in this instance, is entirely dispensed with. Here we see the beautiful and novel valve arrangement by means of which these monster engines are worked. When the engines were first designed, the valves were intended to be worked by the ordinary tappit-motion, because, having no rotary motion in any of their parts, the application of any other but this old arrangement was considered impracticable; but, on starting the engines, it was discovered that this motion did not allow sufficient latitude to admit of their being worked at the different speeds required to suit the varying number of *blast furnaces* that might from time to time be in operation. Robert Wilson seeing that the engines could not be worked satisfactorily with the old motion, at once applied himself to the analyzation of the difficulty, with a view of producing a more efficient arrangement for working the engines, and the result of his investigations was the invention of a modification of the Cornish valve-gear, which, on being applied, was immediately found to answer most admirably every requirement.

The engine-house contains three pairs of engines, each pair consisting of one high-pressure steam-cylinder, 45 in. diameter; one low-pressure steam-cylinder, 66 in. diameter; and two blowing cylinders, each 100 in. diameter—one of the latter being placed about 17 ft. above, and directly over each steam-cylinder; the stroke of all these cylinders being 12 ft.: the steam-cylinders are worked together by means of the large beams before described, of which there are two to each pair of engines. The high-pressure cylinders are placed on the left-hand side of the engine-house, and the low-pressure ones on the right-hand side, and are connected by beams working with *connecting-rods* from the cross-heads. The motion which works the valve-gear is on the low-pressure side, and is carried across the engine-house beneath the floor, so that by means of one set of hand-gear the eight valves of the two cylinders are easily controlled by one man, or worked by the engine itself, as may be desired. This, in itself, is considered to be a triumph of mechanical skill, and the smoothness of action, the perfect accuracy of every part, and the superior style of workmanship and finish of this motion, is of such a character as to attract the attention of even the most unprofessional spectator. The six air-cylinders, each weighing upwards of 25 tons, are placed upon stone piers, and on a level with the bottom of these cylinders is fixed the second gallery, and round the tops of them are fixed airy-like but substantial balconies, which are reached by means of an iron staircase at each end. These cylinders are fine specimens of English workmanship; in fact, there are few engineering establishments besides the Bridgewater Foundry where such cylinders could have been cast, bored, and finished, in the style these are.

*Fan Blast Machines.*—These machines are very common; they are used to urge the fire of steam *boilers*, and at *puddling*, *re-heating*, and *cupola furnaces*, where anthracite is burned; and at cupola furnaces, where coke is used for re-melting pig iron in foundries. Fig. 815 shows a section of a common fan. The two sides of the case are, in most instances, made of cast iron, and held together by the screw bolts *a*, *a*, *a*, *a*. These bolts reach through both sides, and their length is therefore equal to the width of the machine, which varies from 6 to 20 in. The space between the sides is occupied by a strip of sheet iron; this strip determines the width of the machine, and reaches all round the fan, forming the circular part of the case. The wings of the fan, marked *b*, *b*, *b*, *b*, are sometimes of sheet iron; they are fastened to iron arms set upon the axis, and rotate with it, and they occupy a different position in different fans. Some are set radially, others inclined more or less tangentially. Some are straight; others have a slight curvature. On the whole, no marked difference between the one form of wings and the other results, so far as effect is concerned, if no

815.

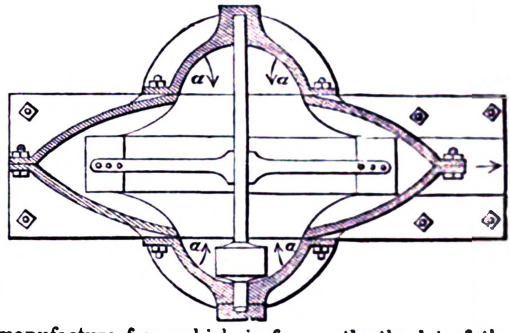



Common Fan.

blunders against the laws of mechanics are made. The fans with curved and short wings do not make so much noise as those with straight, radial, and long wings. The opening *c*, which receives the air, to be pressed out at *d*, must be of greater or less diameter, according to the size of the fan or width of the wings. Broad fans require such an opening on each side. Small fans, of but 6 or 8 in. in width, work sufficiently well with one inlet. The diameter of a fan is seldom more than 3 ft., and from various reasons it can be shown that a larger diameter is of no advantage. The number of revolutions of the axis, or the speed of the wings, is very seldom less than 700 a minute; this speed may be considered sufficient for the blast of a blacksmith's forge and small furnaces. At large furnaces or cupolas, we frequently find the number of revolutions as many as 1800 a minute. The motion of the axis is generally produced by means of a leather or india-rubber belt, and a pulley of from 4 to 6 in. in diameter.

Among the great variety of forms in which these fans have made their appearance, one, shown in Fig. 816, is worthy of notice. The wings of this fan are encased in a separate box; a wheel is thus formed, which rotates in the outer box. Fig. 816 shows a horizontal section through the axis. The wings are thus connected, and form a closed wheel, in which the air is whirled round, and thrown out at the periphery. The inner case, which revolves with the wings, is to be fitted as closely as possible to the outer case, at the centre near *a*, *a*, *a*, *a*; for no packing can, in this case, be applied, and there is a liability of losing blast if the two circles do not fit well.

816.




As the building of this apparatus receives much attention in machine shops, and as the leading principles involved in its construction are very little known, we shall designate such points as may be deemed of great importance by those who manufacture fans, which is frequently the lot of the iron manufacturer himself. The outward case should be strong and heavy; and the interior machinery, which revolves, as light as possible. For this reason it should be made of the best wrought iron, or, what is preferable, of steel. Four wings produce quite as much effect as a greater number. It is, therefore, useless to exceed that number. The greatest attention must be paid to the gudgeons and pans; it is advisable to make both of steel, or, better still, to run the two ends of the shaft in steel points. The wings are to be exactly at equal distances, and of equal weight; otherwise the strongest case will be shaken. The surface of each of the wings should be at least twice as large as the opening of the nozzle at the blowpipe.

The pressure of the blast from a fan is proportional to the square of the speed of the wings, with a given diameter of the fan. The pressure gains simply in the ratio of the diameter, or speed, provided there is the same number of revolutions. The increase of speed is in the ratio of the increase of the radius. The pressure in the blast is produced by centrifugal force. The atoms of air, after being whirled round by the wings, are thrown out at their periphery by a force equal to the centrifugal force resulting from the speed of the wings. This centrifugal force may be simply expressed by $\frac{c^2}{2gr}$; $c$ is the speed in feet per second; $g$ the speed of gravitation in the first second; and $r$ the radius of the fan. According to this, the effects of a fan ought to be far greater than they actually are; therefore a remarkable loss of power must take place in these machines. It is thus very clear that the increase of diameter augments the effect of the machine in a numerical proportion, while an increase of revolutions adds to the effect in the proportion of the square. It is also very clear that an increased diameter greatly increases the friction, while the increase of speed does not augment it in the least. The friction, in these machines, is the greatest objection to their use; therefore the movable parts should be as light as possible. Friction increases in the ratio of the weight, where the materials are the same, but not with an augmentation of speed, at least, not in the same ratio. From practical observation, the following formula has been deduced, in which $a$ is the speed of the fan, that is to say, it represents the number of feet which the wings make in a second; $b$, the surface of the nozzle; $c$, the surface of a wing; and $d$, the velocity of the escaping blast. This formula we conceive to be the proper dimensions of a fan: $d = (\cdot 73) \times \frac{a\sqrt{c}}{\sqrt{b}}$. See CENTRIFUGAL PUMP.

Gwynne and Co.'s improved combined steam gas-exhauster and air-blower, shown in Figs. 817 to 821, is a design of one constructed to pass from 10,000 to 12,000 cub. ft. an hour; but these exhausters can be constructed to any capacity that may be required. On Figs. 817 to 821, B is the case, C the spindle, D the bed-plate, E suction-pipe, F discharge-pipe, G standard for engine, H H slides to piston, I steam-cylinder, K slide-jacket, L disc, M piston-rod, N connecting-rod, O eccentric-rod, P steam exhaust-pipe.

This blower is composed of an outer casing or cylinder B, fitted with top and bottom plates, one of which plates is constructed with a stuffing-box and gland, through which passes the spindle C, on which is firmly fixed an inner cylinder, dotted in the figures. This inner cylinder is slotted through the centre, which slot is fitted with two sliding plates or pistons made air-tight to the slots and working air-tight against the inner periphery of the outer cylinder.

The two cylinders, as shown in the figures, are set eccentrically to each other, so that the bottom of the inner cylinder touches the bottom of the outer cylinder.

When the spindle C is set in motion by the steam-engine or other method, as may be arranged, the slides continue to pass in and out, and thereby take up the air or gas which enters through the pipe E and is expelled through the pipe F.

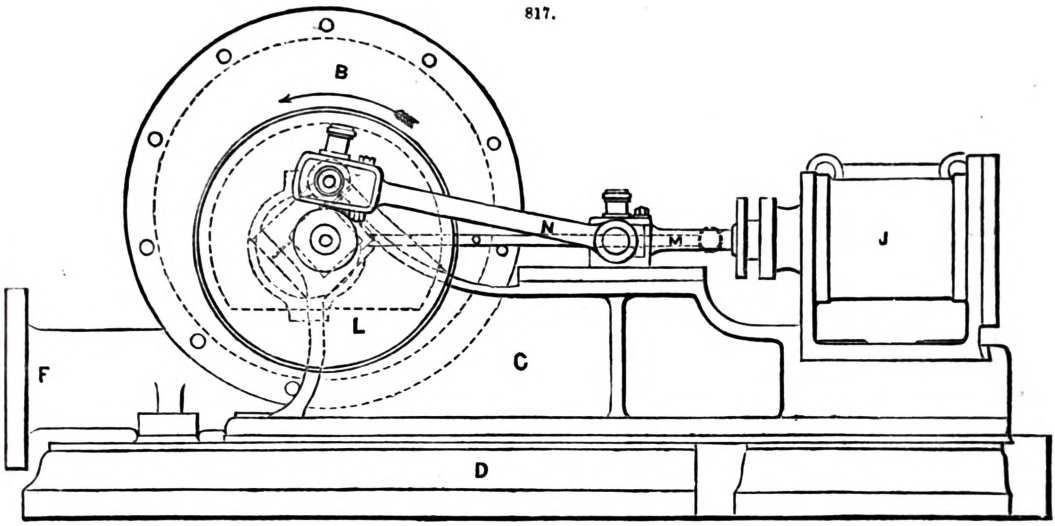
The machine is fixed to a firm cast-iron bed-plate, so as to be perfectly portable; and combining in itself its own motive-power, it requires little or no foundation.

These blowers have been applied most successfully to gas-works and mining purposes, and may be constructed to work up to considerable pressure, if required. One of these exhausters is being very successfully worked by the Llanelly Gas Company.

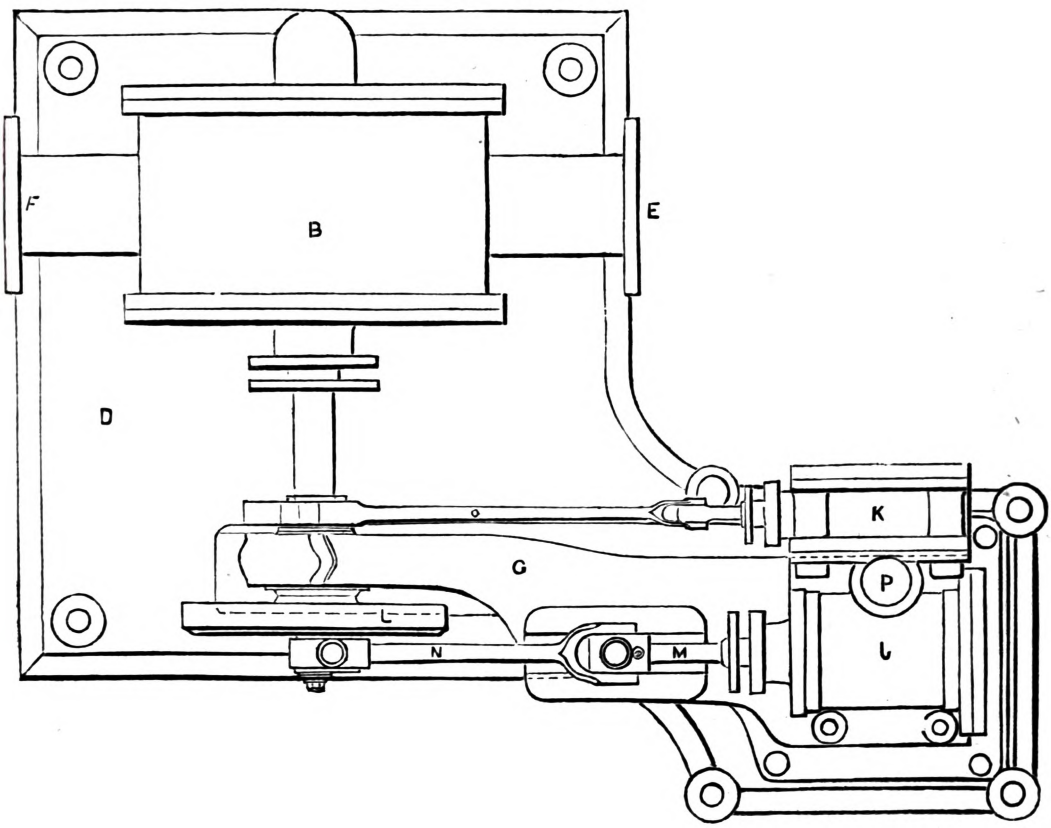
Figs. 817, 818, 819, show the above-specified arrangement.

Figs. 820, 821, illustrate an arrangement to be driven by a strap or by hand-power.

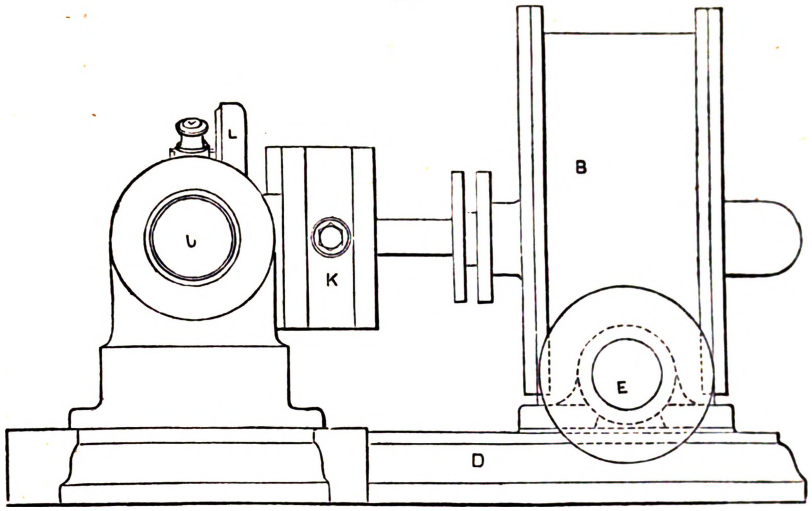
817.



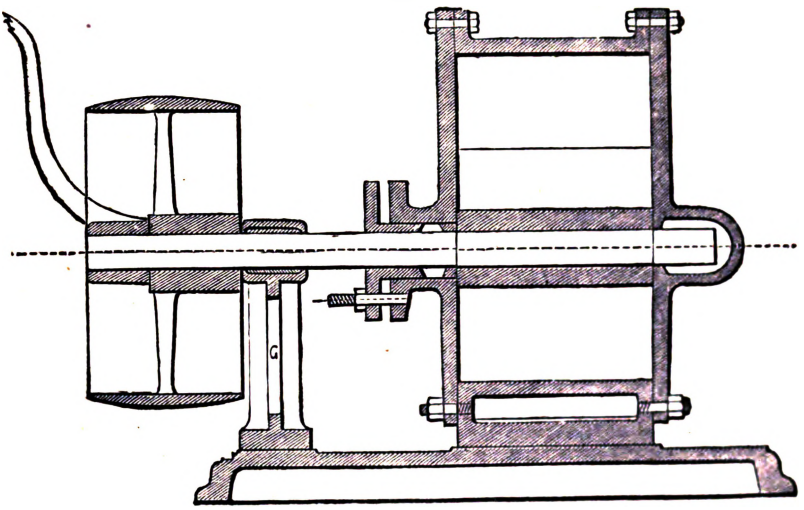

818.



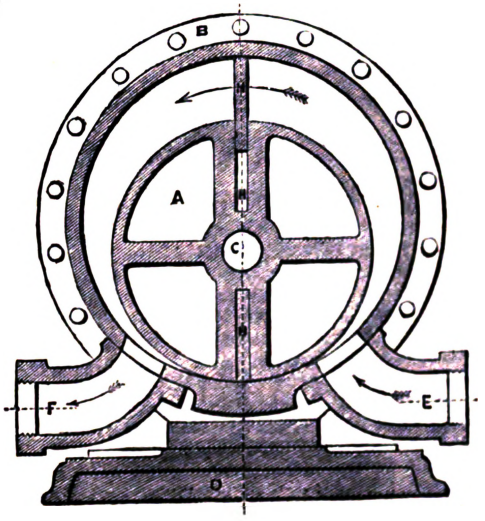
819.




820.




821.



BLOW-OFF COCK. Fr., *Robinet de vidange*; Ger., *Ausblashahn*; Ital., *Chiave di sfogo*.

See Details of Engines.

BLOWPIPE. Fr., *Chalumeau*; Ger., *Löthrohr*; Ital., *Tubo ferrumintorio*; Span., *Canutillo*.

See Assaying. Oxy-hydrogen Blowpipe.

BOARD. Fr., *Planche*; Ger., *Brett*; Ital., *Tavola*; Span., *Tabla*.

*Board*, or *piece*.—Timber cut into thin slabs less than 2½ in. in thickness and more than 4 in. wide are called boards. The term is usually applied to fir and elm, while the same thickness of oak, mahogany, and so on, is generally called *plank*.

Boards cut from 7-in. stuff are called batten-boards, from 9-in. stuff deal-boards, and from 11-in. stuff plank-boards.

822.

Fir boards 1¼ in. thick are called whole deal, and those which are full half-an-inch thick are called slit deal. Boards, Fig. 822, which are thinner on one edge than the other are called feather-edge boards.

BOARD and BRACE WORK. Fr., *Lier l'empanon avec l'arêtier*; Ger., *Verbindung der Halbsparren mit den Walmsparren*; Ital., *Commettitura a canale e tavola sottile*.

This work consists, Fig. 823, of boards with grooved edges, into which thinner boards are inserted.

823.

BOARDING. Fr., *Planchéiage*; Ger., *Bretterverschlag, Bretterwand*; Ital., *Tavolato*.

*Boarding*.—This is a general term for various kinds of work to which boards are applied, as *gutter-boarding, slate-boarding, weather-boarding, sound-boarding*, and so on.

BOARDING-JOISTS. Fr., *Soliveaux*; Ger., *Dielenlager, Polsterholz*; Ital., *Travi del palco*.

See Joists.

BOASTING. Fr., *Ebaucher*; Ger., *Roh-Behauen*; Ital., *Sbozzare*.

*Boasting*, in stone-cutting, is paring the stone with a broad chisel and mallet, so as to leave regular marks like ribbands or small chequers. It is also applied to a margin-draught round the edges of the stone in hammer-dressed work.

BODY-PLAN. Fr., *Section verticale*; Ger., *Spantenrisz*; Ital., *Proiezione verticale*.

In ship-building, the body-plan, Fig. 824, is descriptive of the largest vertical and athwartship section of a ship. This plan fixes by *orthographic projection* the heights and widths of the principal lines of a ship.

The orthographic projection is that projection which is made by drawing lines from every point to be projected perpendicular to the plane of projection.

A horizontal line supposed to be drawn about a ship's bottom at the surface of the water is called the *water-line*, which is higher or lower according to the depth of water necessary to float the vessel: light water-line, the lowest water-line, or that of a vessel when unloaded; load water-line, the highest water-line, or that of a loaded vessel.

The *sheer-plan* is an orthographic projection of the lines of a ship on a vertical longitudinal plane passing through the middle line of the vessel.

*Body-plan, sheer-plan*, and *half-breadth plan*, are on sectional planes supposed to pass through, at right angles to each other, the largest portions of the principal dimensions of the ship. The *half-breadth plan* is descriptive of half the widest and longest level section in the ship. This plane is a horizontal one passing through the length of the ship at the height of the greatest breadth. On this plane the position of any point in the vessel may be fixed by orthographic projection, as to width and length. The three planes on which the projections are established are rectangular co-ordinate planes passing through the centre of the vessel; the three perpendicular lines which transfer any given point to each of these planes are termed the co-ordinates of that point. Naval architects, John Scott Russell excepted, lay down the lines of a ship on the three co-ordinate planes by a good old rule, called the rule-of-thumb, which has not as yet been submitted to mathematical investigation.

In passing, it may be necessary to remark that one naval architect, J. W. Griffiths, works from a model which he whittles out of a piece of soft wood, by the good old rule before named. Upon this system Griffiths has written a large work.

Scott Russell lays down the lines of a ship by well-defined laws, which he establishes by abstract reasoning and experiment.

Russell is a great performer as well as a great thinker; he stands out in bold relief from among the great men of the extraordinary time in which we live. We give from his great work on Naval Architecture his method of laying down the lines of a ship, on what he terms the *compound wave-principle*. Scott Russell says:—

I will begin by taking the easiest problem which can ever be submitted to the constructor of a ship. I will suppose a case, which very frequently occurs in practice, that a certain length of ship is to be built—a certain breadth is given—a certain deepest draught of water and a certain lightest draught of water, and that these are about the ordinary proportions of a ship;—that no particular weight is to be carried, or work to be done, beyond sailing well, or steaming at a moderate speed, and that the purpose to be served is a fair, common mercantile trade, such as ordinary vessels will moderately well perform;—and I will take for granted that the owner expects from the naval architect, what he may reasonably expect from a man of science and skill, that his vessel will be somewhat faster, easier, safer, and more economical, and therefore somewhat more valuable, than a vessel built, without design or calculation, by an unskilled man. This is a task of the most ordinary kind to the naval architect.

There are two ways in which he may set about building his vessel: he may either take the model of the vessel, which is already the best that has been applied to the trade in question, and

improve upon her; or he may at once throw all precedent overboard, and give his employer an entirely new design. The undertaking then will speedily shape itself as follows:—His extreme length and extreme breadth being given, he may determine a midship section, such as will give him the requisite carrying-power, with good sea-going qualities. Next, he will determine a water-line, which will give the highest speed and least resistance of which that length admits; or he may decide to fit her for a given speed only, and adopt a water-line of greater capacity fit for that slower speed. Thirdly, he will adopt a convenient form of deck, for the use and navigation of the ship; and on these principal points he will fill in, what I will call "a skeleton design," and frame an approximate calculation of the qualities of the ship, which we will also call "the skeleton calculation."

*To Construct the Midship Section.*—It is in the choice of midship section that the naval architect is left free to exercise, with the greatest liberty, his own absolute judgment. In the water-line he has little or no choice; Nature has fixed that for him. If he meddle with it, he shows his ignorance or presumption, and Nature sends her due punishment, by refusing to deal kindly with the spoilt water-line; but the midship section he may vary to his heart's content. He may give the ship every sort of quality by choosing it ill or well; and with a given water-line he may produce all sorts of ships.

To illustrate this latitude of choice, and to follow out the consequences which arise from each kind of choice, I will take three midship sections, and carry them through all the stages of design to their ultimate consequence; and I will further suppose it necessary that they should all have the greatest speed the length will allow.

The first of these sections is to carry extremely little cargo, to have little room, but to go as fast as she can be made to go with all the sail and steam-power she can carry. These are the practical conditions of the yacht or the cruiser, the opium clipper or the privateer. What such a vessel requires can readily be contrived, for the conditions given *make* the midship section, and leave very little to the choice of the constructor. Such a ship must be all shoulder and keel, and nothing else;—she will be like a racehorse, lanky and leggy: by being all shoulder, with very little under-water body to carry, she will possess the maximum of power with the minimum of weight;—her fault will be, that she must have an enormous keel, to prevent her from going to leeward; and this great mass of dead wood, or of solid iron keel, exposes a large surface to the adhesion and friction of the water. Nevertheless, it is the form of greatest power with least weight. The bottom of this midship section may be formed in two ways,—it may either be made elliptical, to have a minimum of skin for adhesion, and be reconciled to this deep keel by two hollow curves; or it may be reconciled to the keel by a long wedge-bottom. I prefer the elliptical bottom for iron ships; but the other, or peg-top shape, has been much used in wooden ones. See Figs. 824, 825, 826.

I will next suppose that the capacity, thus got, is too small for carrying remunerative cargo, and that a cargo hold, of a capacity more usual with mercantile vessels, is required; in that case I keep the same shoulders, and give a larger under-water body. See Figs. 827, 828, 829.

I will now take a third design. The ship is to carry as much as is not inconsistent with good sea-going qualities; and she is to have room, also, for boilers and machinery of considerable power. This requires her sides to be nearly upright, her bottom dead flat amidships, with only so much off her bilges as will not be inconsistent with what she is to receive inside. This the form and arrangement of her boilers and machinery will generally determine, and the boilers and machinery in such a vessel should be treated as ballast, and kept low. See Figs. 830, 831, 832.

In regard to these three midship sections, it is to be noticed, that they are prescribed in some measure by the uses of the ship; but the forms I have mentioned come entirely from the judgment of the constructor, and whether they have been wisely or injudiciously selected, must be judged of after the calculations have been made of the various qualities to which they give rise.

But there are one or two points which occur to a constructor, at the first glance at these forms of under-water body. It is plain, the first is easiest, and the last hardest, to drive. It would require much more sail to drive the two last, than the first; and it is equally plain, that the first is much better able to carry sail than the last. The area of midship section of under-water body is the thing to be driven; the area of the sail is the driving-power: but the power of the shoulders to carry the sail upright limits the quantity of sail the ship can carry. The bulk of the under-water body brings with it two evils,—resistance to being driven through the water, and under-water buoyancy tending to upset the ship.

It is plain, from these considerations, that the first shape is suited for a fast ship under sail alone, the last is suited for a fast ship under steam alone, and the middle form may do for a moderate quantity of both—for what is called "the mixed system."

Of these three vessels we may also form the following augury, before proceeding to precise calculation. The first ship may be powerful, weatherly, lively, and fast. The last vessel may be tender, easy, sluggish, and roomy. By a proper mixture, we may obtain, in the intermediate vessel, any compromise among these qualities for which we have a fancy. In this choice there is ample room for the display of skill and the exercise of judgment; but it will be first necessary to complete our skeleton design and our trial calculations.

We have said nothing as yet about the parts of midship section above water: but it will be noticed, that these grow naturally out of the form adopted under water; and it will be observed, that we have proportioned the above-water body to the under-water body. The object of this is to give adequate lifting-power in a sea-way, in proportion to the heavier under-water body: but of this we shall have more to say.

In three designs, the midship section (so-called) is far from being actually amidships, being placed at the point of greatest breadth, or nearer the stern than the bow, in the proportion of 4 to 6.

*To Construct the Chief Water-line.*—For the side-view of a ship, or vertical section, draw a horizontal line, representing her whole length at the main water-line, and erect at the ends of it two perpendiculars. This line I shall call henceforth *the length of the ship, the length between the perpendiculars, or the construction length.* These perpendiculars, also, are to be ruling elements of construction, and will be called *the perpendiculars.* Divide the length between the perpendiculars into ten equal parts; take four of these abaft for the length of the run, and six of these forward for the length of the entrance. Describe a semicircle on each half of the chief breadth. Divide the length of entrance and this semicircle into any, the same number, of equal parts; the distance of the water-line from the centre-line, opposite each division in length of the entrance, will be the distance of each corresponding division of the semicircle from the same centre-line, and a line through all the points thus found will be the true wave water-line of the bow. The water-line of the run will be different from this in one respect only,—it will be necessary to draw parallel lines to the centre-line through each of these divisions of the semicircle, which it may be convenient to call *the semicircle of construction*, as shown in Figs. 826, 829, 832. On each of these lines points may be found, just as if it were a bow-line. These lines must be prolonged aft beyond the points thus found to a distance equal to that part of the line intercepted between the semicircle of construction and the main breadth. The last-found points in the parallel lines give the line of main breadth.

Thus we have formed the chief water-line of the bow and of the stern, or the lines of entrance and of run for the greatest speed which the given length will admit. The lines thus given are absolute, and will admit of no deviation without some loss. Nevertheless, some modification in the application of these lines may be admitted as expedient, and one of them is obvious. It will be seen that the point of the bow is so extremely sharp, that it would be in continual danger of cutting everything which it touched, and, being as fine as a razor, would run risk of being crushed by rough usage. The stem also, for the rough work of a ship, must be of a considerable thickness; and the practical question at once arises: How shall we alter the line at the bow to get this thickness? Shall we cut the fine part off, and shorten the vessel? To this the answer is, that if you do, the vessel will have become too short for the length settled. The way I use, is to draw the bow to a few feet longer than I intend to retain, and then to cut off the excessive length of this water-line to the exact length that I want to keep. I thus find a thickness of a few inches remaining between the two sides of the water-line, which is just thick enough for the materials of the stem: by this means I get the extreme length I require, and I also get the strength of stem, which is necessary for durability and bad usage; and it will be noticed that the bow, which I thus gain, is of slightly greater capacity than the first attenuated line. This I call, therefore, *the corrected water-line of the bow.* No such adjustment is necessary at the stern: it is enough there to insert the stern-post, simply by increasing the breadth between the lines to admit the thickness of the stern-post,—a deviation insufficient to cause a sensible difference in the performance of the ship.

There is another modification of these water-lines of the fore-and-after bodies, which may require further consideration. We have put both entrance and run in the same plane, with the intention of leaving them so in the construction of the ship; but this is only our first intention, and we must be prepared afterwards, on good reason shown, to change it. The main water-line may require to go lower or higher in the vessel than we now propose, and the after-part of it may have to go higher or lower than the fore-part, in order to gain some advantage; but we shall effect this change, if necessary, without in any way altering the character of the line already drawn: we shall only alter the height at which it should be placed, and that we shall not do unless required.

*The Sheer-plan.*—This gives the entire outline of the ship, as we look at her sideways, Figs. 825, 828, 831. The top line, or upper boundary, is the line of her deck or bulwark, or, in short, the top of the ship, which must be laid down in order to construct the chief buttock-line in section (4); the bottom is the line of her keel; the front is the line of her stem, or cutwater; and the after-part is the line of her stern-post.

I begin with the stem. I make that line follow the form of the chief buttock-line, and gradually grow out of it. This ought to be so, because buttock-lines bound equal thicknesses of the ship, and a stem is merely a thin slice of the ship, and therefore follows one of the buttock-lines. As a matter of beauty and of reason, therefore, it must be made a buttock-line, in order that its outline may harmonize with the general form.

The form of the stem, therefore, will depend on the decision taken with regard to the deck-line and the buttock-line. If the deck-line be kept well aft, so that the main buttock-line tumbles home, the stem above the water will be curved backwards, and so be in unison with the tumble-home bow; and it will be the contrary, if the fashionable clipper-bow be adopted. Above the water, however, the mere form of the stem itself is a matter, to some considerable extent, of taste or fancy. If the general character of the bow give good buttock-lines, it will not much matter whether the stem to which they are joined curve out or in, except that it will be always more comely that the stem should harmonize with the character of the bow, of which it forms a conspicuous outline. Men who hesitate to give it a decided character, express their imbecility by leaving it perpendicular.

Below the water, on the contrary, the form of the bow is of the greatest practical value. It has long been usual in this country to carry the stem down to an angle with the keel, to continue the keel far forward to meet the stem, and so form what is called *the fore-foot* of the ship, giving it a great gripe, or hold, of the water. This gripe and fore-foot have every bad quality,—being weak in structure, and making the vessel hard to steer. I systematically cut it all off, following the shape of the other buttock-lines; and, further, I carry this rounding a great way back,—perhaps to one-sixth of the whole length of the ship. By this I not only diminish the fore-gripe and ease the steerage, but I keep the stem and the fore-foot out of harm's way; and I have often known

this both to save repairs and to contribute to the safety of the ship. When turning round in narrow channels, when steering in intricate or shallow waters, or performing evolutions under difficult circumstances, the fact that there is no thin, protruding part near the bottom, to touch or strike the ground, to be broken off, or to impede or alter the movement or direction of the ship, is often of the very highest consequence. By a gentle curve at the stem, therefore, I keep the fore-keel and the fore-foot out of harm's way; and I generally do the same at the stern, where dead wood can be spared. By curving the after-part of the keel upwards, like the stem, we may often save both keel and rudder, and we certainly facilitate the ship's coming round. Of course it is done to a much less extent at the stern, as several feet of gripe at the bow will correspond with a few inches of trim by the stern.

But, while I thus curve the keel and fore-foot, I keep the whole central part of the keel perfectly straight, but for no other purpose than to be able to support the middle of the ship on blocks in the dock. This is an obvious necessity, for otherwise the keel would rest only on points, instead of being uniformly supported; and in the dock it is rather an advantage than otherwise, that the two ends of the ship should not be borne by the blocks, unless they should require special repairs, for which purpose they must be propped up when needful.

We have as yet said nothing about the inclination of the keel. It is not necessary that it should be parallel to the water-line, except where there is a narrow limit to the extreme draught of water, in which case the keel should be parallel to the load water-line: in most other cases it should incline downwards at the stern, so as to draw more water abaft than forward. In the case of screw-steamers of large power, it is imperative to have this draught, in order to get the screw sufficiently large and sufficiently under water for effective power; and further, it is convenient, in sailing vessels, to be able to carry a large sail area on the after-part of the ship, for which greater depth of keel aft than forward affords the necessary facility. It is convenient frequently, for the same purposes, that a vessel, when light, should draw very much more water aft than forward, and that her lading should bring her down gradually to even keel. It is usual to call this greater draught aft than forward, technically, *the difference of the ship;* and it is reckoned a main element in her trim.

Another element in the sheer-plan is the rake of the stern-post, and this also is a matter in which great licence can be allowed to the constructor, as it affords him great resources, out of which to further the uses of his ship. He may either plant his stern-post straight up and down, so as to make the rudder pivot fairly; or he may throw the head of the rudder back behind the perpendicular, at an angle; or he may throw the heel of the rudder forward of the perpendicular: indeed, he may make the line of the rudder cross the perpendicular at any angle he may choose. In the first case, he will maintain the balance of his original draught. In the second case, he will extend the dead wood and increase the lateral resistance of the ship to leewardliness. In the third case, he will diminish the lateral resistance, but increase handiness. In every intermediate degree between these two, he will gain one of these qualities at the sacrifice of the other.

The effect of this inclination on the rudder itself must not, however, be forgotten. The inclination of a rudder increases its power to turn the ship, but it also increases the resistance which the application of rudder offers in every degree to the progress of the ship through the water. The action of the rudder, as has been already stated, is of the nature of a hindrance to one side of the ship, so as to allow the other side to go forward with greater speed, and thus turning the ship: but the inclination of the rudder-post has a double effect, by which, when the rudder is held over, not only is one side of the ship hindered, but a certain quantity of the water which strikes the rudder is diverted upwards as well as to one side. Nevertheless I have no hesitation in recommending a certain amount of rake of stern-post to be given where very great power of rudder is wanted.

Next after rake of stern-post comes the question of rake of counter and rake of stern. I am in the habit of allowing the buttock-lines to decide for themselves the rake of the counter, so that when the stern is deep in the water the counter may be a continuation of the true form of the ship and of her lines. A good counter of this sort will, therefore, help the ship, instead of hindering it, especially when the stern happens to be buried in the waves. As to rake of stern, I am not sure that that is more than matter of fancy: excepting for convenience, it is better that the stern should rake outwards, than that it should tumble home; and even the Americans, who have extremely small sterns, always give them some rake.

We have not yet done with the sheer-plan. The upper bounding-plan, or that which appears to the eye to finish the ship above, is called the *sheer-line* This also has been called matter of taste merely; but some points of it have more or less reason. It is a matter of fact that, in looking at a ship the upper bounding-line of which is perfectly level, she is apt to have the appearance, contrary to the truth, of being rounded down,—that is to say, with a hump in the middle and a droop at the ends; and this is universally agreed to be so ugly, that considerable spring at the bow, and somewhat less spring at the stern, are necessary to counteract it. From experience one may say, that in a vessel 200 ft. long it requires about 2 ft. of rise at the bow and 8 in. at the stern to make her seem straight, and as matter of beauty and custom this is generally exceeded.

So much for the quantity of sheer, or spring, to be given fore and aft. The quality of it depends on the exact curve which may be adopted for the sheer. I adopt a parabola as the sheer-curve, and proceed as follows. Dividing the vessel into ten equal parts, six forward and four abaft, I rise forward successively 1, 4, 9, 16, 25, and 36 in.; and abaft, ¼, 2, 4½, and 8 in. This gives a total spring of 3 ft. forward and of 8 in. aft, and makes the bow 28 in. higher out of the water than the stern. This proportion will serve very well from 200 ft. long up to 700 ft., as the larger vessel does not require an increasing spring; but for smaller vessels than 200 ft. these quantities would be in excess. Nevertheless it is to be observed that, even in very small vessels, especially when low on the water, a considerable spring forward is useful to keep them dry. I am, therefore, of opinion that there would not be much harm in extending my proportions, given above, to a con-

siderably smaller size of vessel than I have stated. However, it is not a matter on which there is anything dogmatic to be said.

The sheer-line is important in its structure thus far, that it is usual to make the planking of the upper part of the ship, the line of ports, and the lines of the decks, follow the line of sheer: I say, *usual;* but I have found it very convenient and useful to deviate from this practice, and to make the decks follow any line that may be convenient for the internal arrangements. For example:—where I have wanted to obtain a large and roomy forecastle without deforming the vessel by raising this forecastle above the bulwarks, I have obtained it by running the line of the deck straight forward on the level, and so following the level of the water-line, instead of the sheer of the bulwark. In this way, the height of the top of the bulwark above the deck, which amidships might be 5 ft., might become 8 ft. at the stem; and I am not aware of any practical inconvenience arising from this, which is not much more than compensated by strength and usefulness.

*To Construct the Chief Vertical Longitudinal Section, or Buttock-line.*—In the construction of this line there is much room for judgment; for, although it can hardly be said to possess such remarkable properties of its own as the water-line and midship section, it has the power of either increasing the good qualities or aggravating the evils which the ship will derive from those two primary lines. It is only secondary in importance to these; because by its means all the possible good springing from the others may be favourably developed, marred, or neutralized. It happens also that this has not heretofore received the attention and study it deserves; in most designs it is not even to be found. In my belief, its good qualities tend materially to the ease, dryness, comfort, and safety of sea-going ships. Inland and fresh-water ships may perhaps neglect it with impunity; but a practised eye can detect in the faults of this line almost instantaneously the bad sea-going qualities of a defective design.

I place the chief buttock-line in a vertical plane parallel to the plane of the keel and the perpendiculars, or central plane of the ship, and at one-fourth of her breadth from this plane on both sides.

In ordinary ships this line will be found to be of a most variable, vague, and nondescript character. I have adopted for it the vertical line of a sea-wave, and I believe that its conformity to that shape has everything to do with the ease of the vessel at sea. The vertical section of the common sea-wave is the common cycloid. This must be elongated for a long, low vessel, and compressed for a short one. Three points through which it must pass have already been determined by the midship section, and by the water-line; because, as this line is distant from the centre one-fourth part of the breadth, it must cross those three lines where they cross this vertical plane.

These three are, however, the only points which do not admit of free choice; and it remains a part of the skill of the constructor to adopt such a cycloid as may consist with his general design and with the use of the ship. Each of the three midship sections, Figs. 824, 827, 830, which I have given, places the bottom of the buttock-line at a different depth under the water, and each of the three requires a different cycloidal line to fit it. The nature of this cycloidal line has been for a few centuries known to mathematicians and philosophers as the only line in which a pendulum can so swing that its vibrations, whatever their extent, shall be equal-timed. It happens that there is a remarkable analogy, as we have already seen, between the swing of a pendulum and the roll of a ship; there is an equally strong resemblance between the forces which exist in a wave and the forces which act on a pendulum: the mathematics of a wave and the mathematics of a cycloidal pendulum are nearly identical.

When therefore, says Russell, I discovered that the forces which replace the water in the run of a ship are of the same nature as the forces actuating a wind-wave at sea in the vertical position, I naturally found in this discovery a key to the vertical lines of the after-body of a ship; and I contrived the vertical lines of the fore-body, in the belief that wind-waves coming into collision with a body already perfectly fitted to the form which they themselves take in undulating, unresisted, free motion, would not be broken, but would have free way, and that they glide as smoothly over the face of a solid cycloid as the layers of the same wave glide over one another. On putting the question to the waves themselves, they decided that it was so, and a vertical cycloid thus became the buttock-line of the bow of an easy and dry ship above the water, just as it had already become the easy run of the wave of replacement in the stern of the ship.

The chief buttock-line, therefore, is described in the following manner:—The after-part is formed from a semicircle, the bottom of which is at the intersection of the midship section with the vertical plane, and of which the uppermost point is as high out of the water as we choose to carry the bulwark. From this we describe a cycloid, as shown in Figs. 825, 828, 831, and we cut off as much of this cycloid as we choose, to adapt the portion of the stern beyond the perpendicular, a point which is a matter of room and comfort merely. For the bow we have the choice whether it shall much overhang the water, or rise up pretty square, or tumble home. For a vessel low in the water I sometimes adopt the first; for a vessel high out of the water, never. I believe that, on the whole, a tumble-home form of bow is the dryest and easiest at sea; and there is also the vertical cycloid between the two. Each proportion and kind of vessel has its corresponding cycloid. In the case we are now considering, the vessel with a small under-water body has a flare-out bow. The fuller under-water body has a vertical buttock-line, and the fullest has a tumble-home bow. The first, Fig. 825, of these gives what is called *the clipper-bow.* The second and third, Figs. 828, 831, give what I may claim, says Russell, to call my bow. This bow has the quality of giving roundness, fulness, and capacity, in combination with the fine, hollow, unresisting entrance of the wave water-line.

*On the Main-deck Line.*—I call the main, or chief deck-line of a ship, the outline of that deck which is meant to be kept in all circumstances well out of the water, and in ordinary circumstances not to be swept by the waves. It is this which constitutes the chief gun-deck of a war-vessel, on which it is necessary, in all ordinary weather, that the ports should be open without the sea entering. There have been war-vessels in which this deck was generally under water; but they, after long experience, were named *coffins;* so I shall keep my definition.

The choice of a deck-line has everything to do with the usefulness of a ship for its purpose, more even than her behaviour at sea. This main or construction deck is, in small vessels, the uppermost deck, but in larger vessels there is a spar-deck above it; in a three-decker there are three decks above it, and in the GREAT EASTERN there are four decks above it and four below. As a general rule also, when a vessel is deeply laden, this deck is an eighth or a tenth of the beam of the ship above the water.

A little consideration of the purposes a main-deck has to serve will help to indicate how various its shape should be. In a vessel meant to be fast, one would wish its point to be like the rest of the bow of the ship, fine and sharp, because, if we put a full and bluff deck on the top of a fine fast bow, we not only give the vessel many bad qualities in pitching in a sea, but the fulness of the deck-line will be continually taking speed from the ship whenever the sea meets it, and so counteracting the very quality we meant to gain by giving a sharp bow under water. This argument in favour of sharpness appears at first sight inconsistent with the quality of a roomy fore-deck, which is to be obtained by a great, broad, bell-mouthed bow, flaring out wide over the surface of the water. Such a bow the old school and our Dutch neighbours dearly love and still believe in; and we should never have succeeded in introducing the fine sharp deck aloft, in opposition to the traditional prejudices and professional proverbs, in which the wisdom of seamen has come down to us, but for the fact, that the full projecting deck-line aloft has been found fatal to speed, and especially to speed in bad weather. There can be no doubt that in fine weather a large roomy bow on deck is a handsome and agreeable thing; all the work of the ship can be done in it comfortably and handily. There is room for everything, and to spare; nothing is huddled up, and you can get freely about everything: all this can be said with great plausibility and some truth, and it is still more applicable to a ship of war than to a merchantman, because, in chasing, it is desirable to lay two long guns parallel to each other in the line of the keel, and to be able to run them out through two bow ports, clear of everything, and to work them comfortably in that position. It was long pretended that it was impossible to do this on a sharp, fine deck-line, and for many years did Admiral Berkeley delay the improvement and stop the speed of our finest ships, for this crotchet, which in the end turned out to be a crotchet, and nothing more.

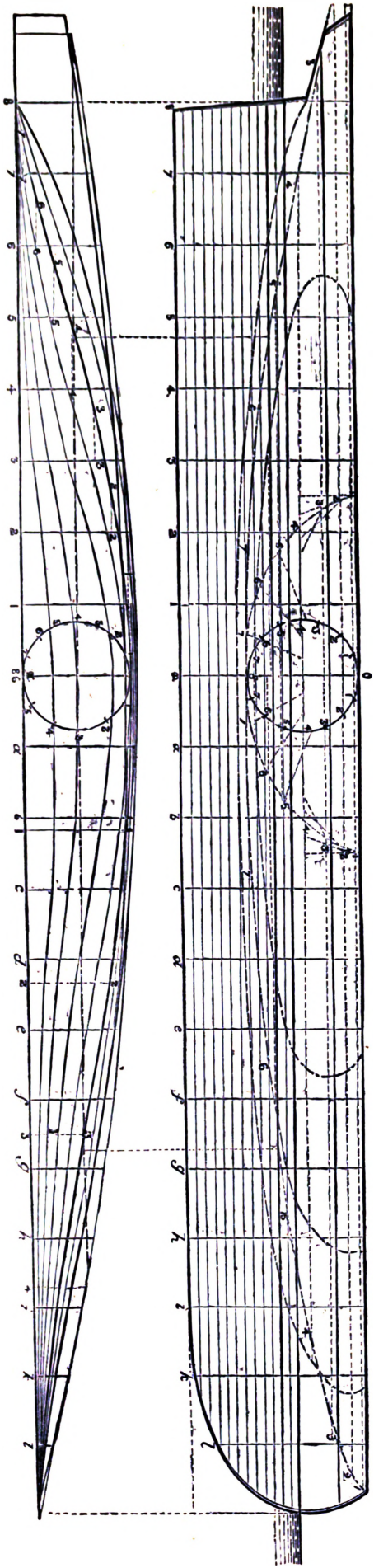
The simple fact is, that the roominess, dryness, and comfort of a full deck-line, instead of a fine one, is, impression or belief, and nothing more. If you imagine that a fine bow is got by cutting so much room off a full bow, and so diminishing the extent of available deck-room for working the ship, you may consider the fine bow as narrow, confined, and inconvenient; but the practical fact is the contrary to all this. The fine deck-line of a modern fast ship is not got by cutting anything off the length, or off the width, or off the roominess of a deck; the sharp bow is got by adding on a fine entrance to a bluff one, and by lengthening the deck: the full parts of the ship and of the deck remain where they were. All that is necessary, therefore, is to take care that the work and working parts of the ship shall, in the fine bow, be kept well back in the broad open space of the deck, and not crammed forward into the narrow space, which has been superadded, and which should be kept perfectly clear and unhampered. It is also a further peculiarity of the fine bow and fine deck-line, that the foremast stands much farther aft than in the old full bow, and that there is, therefore, more room before the mast: care must, therefore, be taken to keep windlass, capstan, catheads, anchors, and all the working parts in the bow, well aft,—not to give room merely, but also to keep heavy weight, as it always ought to be kept, out of the extreme bow of the ship.

There is another way of looking at this matter. I am very fond, says Russell, of covering in the whole of the fine part of a deck forward with a light forecastle bulkheaded off, especially in iron ships. It is a great convenience, and forms capital quarters for the crew: it keeps the head light and dry; and immediately abaft the forecastle a broad, roomy deck is still to be found. But there is another way of giving a roomy deck, that is, a wide one, on a sharp-bowed vessel. I have done it in vessels of war with perfect success, so as to make an extremely fine bow carry two long 8-in. guns parallel to the keel, through two comfortable ports, with ample room all round to work and train them freely. This I did by shortening the deck, or stopping it very much short of the bow, carrying the bulwark round the bow considerably behind the stem; the real deck beyond the bulwark forming part of the head, which, instead of being grated and overhanging the sea, had a solid oak deck over the greater part of it, leaving the head as convenient as before for all practical uses. In this way the bulwark of the deck left the real line of the ship 30 ft. short of the stem, with a fine, round, roomy deck to delight the heart of a commander of the old school, by giving him all he wanted on the inside, without impairing the form, which the sea demanded, on the outside.

There is yet another way of planting a full, round, capacious deck-line on a fine, hollow, fast water-line, and yet perfectly reconciling them to one another, so as to form a handsome, symmetrical, sea-going ship. This is to carry out the tumble-home bow. Of this system I am a warm advocate: it makes a vessel dry, easy, and safe. For a long time there has been much prejudice against it. The rising generation will probably adopt it largely: for the length and size of vessels will increase rapidly, and render it unnecessary to seek room by means of an exaggerated bow-line over a fine water-line. To carry out properly this system of tumble-home bow, it is only necessary to take a tolerably full, easy deck-line, composed of two circular or two parabolic arcs, laying them over the water-line, and so far behind it, as to be easily reconciled with it, by means of the cycloidal buttock-line; a process which will be guided, in a great measure, by the point at which the cycloidal buttock-line, already drawn, meets the level of the deck.

In the stern, there is even greater scope for management and fitting for use. I believe in large, capacious, roomy sterns. I think room can be got there with less cost and sacrifice than in any other part of the vessel; and hence the sterns of my ships have been called, by those who delight in small, narrow sterns, "Scott-Russell's ugly sterns." A small, handsome, light, little stern, may be eyesweet and pretty, but, to my mind, it is a costly whim. I scarcely know any good quality of a ship which is not improved, or any economy which is not enhanced, by a large, roomy stern and

826. 825.



deck-line. In a merchantman it gives large passenger cabins, airy as well as roomy, and in that part of a ship which pays the owner best. In a ship of war it gives a magnificent roomy poop, and plenty of space for working the stern guns; which however are, perhaps, seldom wanted in a British ship of war. There is yet this further recommendation beyond all,—that the roominess and fulness of the stern in the neighbourhood of the deck-line is the greatest element of safety in the ship's most perilous position, of running before a heavy wind in a storm, and in most circumstances it may be used with advantage to enhance the stability and sea-going qualities of the ship.

The best way to turn the stern to advantage, for room and wholesomeness, is to carry the breadth on deck well aft, to taper the ship in towards the stern but little, and even, if necessary, to carry the projection of the stern a good way abaft and beyond the perpendicular, following, however, and not extending beyond, the vertical buttock-line already given. Here we may steal a great deal of room from the sea.

An early question arises: Shall we make the

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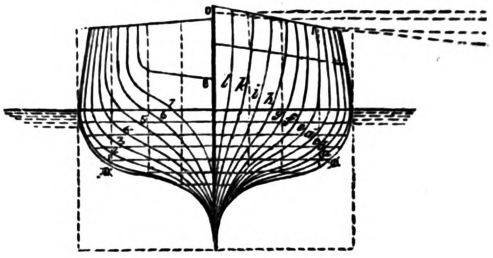
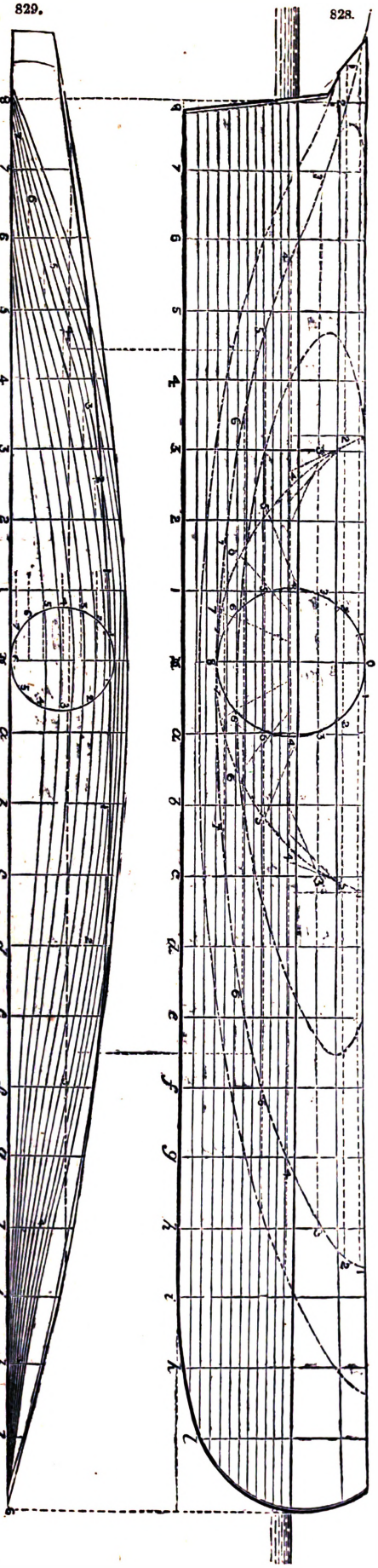


| | Feet. |
|---|---|
| Length on load water-line .. | 150 |
| Breadth extreme .. .. .. | 24 |
| Depth at the side .. .. .. | 16 |
| Tonnage O.M. .. .. .. | 415$\frac{43}{94}$ |

stern round or square? I answer,—Its bulk is the main point: its shape is of less consequence. If you like, as a matter of taste, to cut the corners off, it becomes a round stern; and nothing is more common than to see people cut off the stern inside, and then stick something on the outside, to make up in appearance for the corners cut off. When very little is cut off the corners, it has been common to call it an *elliptical stern*, although it never is an ellipse; and when much is cut off, the stern is called *round*, although it never is circular. My own opinion about the precise outline of the deck astern is, that, so far as the qualities of the ship out of water are concerned, it is of little importance.

The constructor is now prepared to adopt a definite form for his deck-line, which is plainly a compound affair of policy, diplomacy, and taste. For a trial line I should use, forward, two arcs of a circle, intersecting at the bow, and having their centres on a line drawn athwartships, half-way between the perpendiculars; thence I should incline by two parabolic arcs, gradually narrowing to the breadth of the intended stern; and, for that breadth, I should adopt, at the point where it passes the perpendicular, some specific proportion—6, 7, or 8 tenths—of the midship breadth; finishing with whatever straight line or curve may have been determined on, as regards room at the stern. Indeed, in a vessel of no great



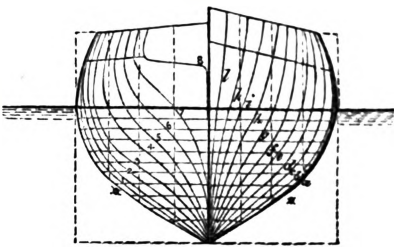

length, and without much overhanging counter, I cannot see any harm likely to arise from carrying the full breadth of the deck amidships right aft to the stern, with merely sufficient curvature to give an agreeable line.

The completion of the design now requires us to reconcile these four ruling lines of the ship with one another. In this operation, what the constructor must keep mainly in view, is to extend, as far as possible, through all the remaining lines of the ship, the good qualities which have been established in the ruling lines.

*To Construct the remaining Water-lines.*—It is most desirable that the water-lines of the entrance should be as exactly as possible of the same form, on reduced breadth, as the main water-line. There will be some difficulty in doing this, especially near the keel; and the tendency of these lines will be to elongate themselves forward. This is to be avoided.

The remaining water-lines of the after-body are to be constructed on nearly an opposite principle. They are to deviate rapidly from the chief water-line of the after-body already drawn; and

827.

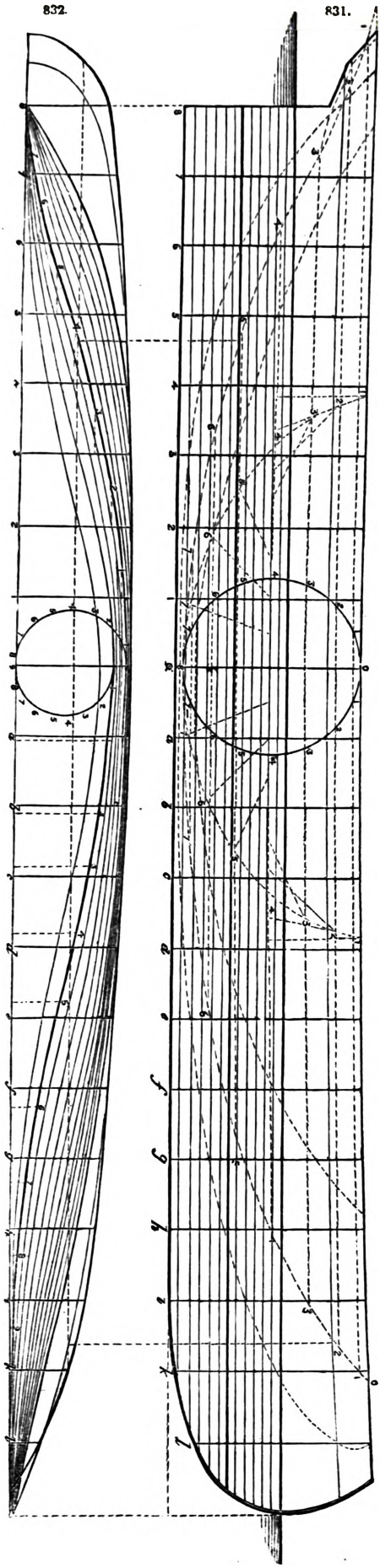


| | Feet. |
|---|---|
| Length on load water-line .. . | 150 |
| Breadth extreme .. .. .. | 24 |
| Depth at the side .. .. .. | 16 |
| Tonnage O.M. .. .. .. | 415$\frac{43}{94}$ |

this they will do naturally, because the main buttock-line, which rules the after-body, compels the water-lines to increase rapidly in fineness, as they go down in the water, and to extend rapidly in fulness, as they rise to the surface; thus giving what I believe to be the best kind of stern, namely, very fine below and very full above. In this respect it is a contrast to the bow, which is kept as full as may be, consistently with the chief water-line, all the way down.

It is desirable to have at least three complete water-lines, in order to form a first approximation to the complete calculation of the ship.

*On the Completion of the Vertical Cross-sections, or Body-plan.*—The cross-sections are all to be regarded as midship sections modified, but each of them giving, to the part of the ship where it lies, qualities which either enhance the good qualities of the midship section, or impair them. A vessel, with a fine, powerful midship section, may easily be impaired by feeble ends, and a weak midship section may be reinforced by good cross-sections, especially in the after-body. What the designer has to bear in mind, then, is to study how far he can enhance, support, and carry out the qualities of the main midship section in the rest of the body. In this attempt he will be materially aided by the choice which he makes of that cross-section which passes through the after-perpendicular. To this frame, being absolutely out of the water, he is free to give any

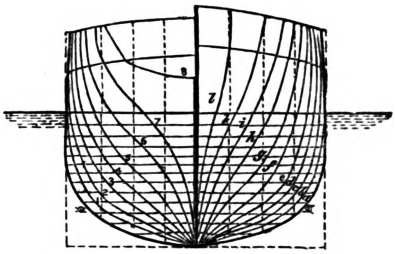



shape he pleases; and having fixed this, he will find that, with the main buttock-line, it rules the entire form of the after-body, and also controls materially the surface water-line of the stern. It is this stern cross-section which I am in the habit of making very full, in order to turn the after-body to the best possible account. Great caution, however, has to be observed, not to make this fulness abrupt; otherwise, when rising and falling in the sea, the counter will be apt to strike the water with violence.

The circumstance, that this portion of the vessel remains so entirely subject to the free will of the designer, makes it, for the inexperienced, the most difficult part to decide and determine; and a greater variety of forms will be found about the region of the stern above the water, than in any other part of a ship. The learner will, therefore, naturally be disposed to take this from the best examples he can find, and for which I refer him to the best vessels engraved in my work.

The vertical sections of the after-body, followed out in the manner I have indicated, will be found, as they approach the stern, to have become very fine below and very full above; and

830.



| | Feet. |
|---|---|
| Length on load water-line .. | 150 |
| Breadth extreme .. .. .. | 24 |
| Depth at the side .. .. .. | 16 |
| Tonnage O.M. .. .. .. | 415$\frac{44}{94}$ |

so they ought to be: but in the bow there will generally be found a similar tendency of the lines to become extremely fine below, and to grow full above,—and there it is necessary to counteract this tendency, instead of encouraging it, as abaft. The bow cross-sections must, therefore, be made to maintain their full breadth well down towards the keel; and care must also be taken that they do not spread out rapidly at the surface of the water, and above it. The reason why the fulness should be preserved below is, that the business of the fine part of the bow, or cutwater, is to displace or remove the water out of the way of that part of the ship which is to follow; and if the bow part be cut away too fine, this work will not be done, and the part behind will still have the work of displacement, with a bluffer entrance, and a shorter time to do it in,—which is the same as to say, that it would then require unnecessary force, by causing unnecessary resistance. The main water-line having, therefore, already rendered the bow sufficiently fine for the service of dividing the water, care must be taken not to carry this fineness further than necessary, or than it is carried in the chief water-line.

Moreover, much care will be needed to prevent the cross-sections of the bow from flaring out very much, to meet the line of the upper deck. To avoid this, we have recommended that line to be kept fine, and to be thrown as far backwards from

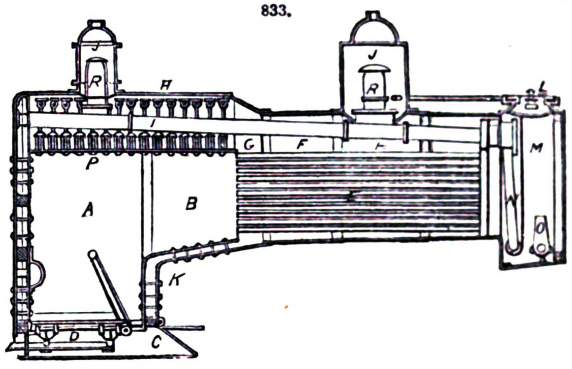
the fore-perpendicular as conveniently practicable. Moreover, the cycloidal buttock-line, properly used, will help to throw the deck back, and to prevent it from spreading over the fine bow: nevertheless, it will always be a matter of great difficulty to reconcile the wave water-line, the full deck, and the cycloidal buttock-line; but when it is well done, it makes the most beautiful, as well as the best, of all sea-bows. For fresh-water bows it does not matter how much the deck flares out, or how much it overhangs the water: it is in the sea that the true skill of the accomplished naval architect is to be developed. It is not the best voyage in fine weather, but the best behaviour in bad weather, which gives reputation to the truly seaworthy ship.

BOILER. Fr., *Chaudière à vapeur*; Ger., *Dampfkessel*; Ital., *Caldaia*; Span., *Caldera*.

A boiler is a strong metallic vessel, usually of wrought-iron plates riveted together, in which steam is generated for driving engines, or other purposes.

Fig. 833 is a section of a locomotive boiler; A, fire-box; B, combustion-chamber; D, grate; C, ash-pan; K, water-legs; P, crown sheet; H, wagon-top; I, steam-pipe; J, steam-dome; G, gusset; F, barrel; E, flues; N, breeches-pipe; M, smoke-box; L, saddle; O, blast-pipe; R, dry-pipe.

833.




A *steam boiler* generally consists of a fire-box, where the combustion of *fuel* occurs, and flues, through which the products of combustion pass into the chimney. These parts are made of thin metal, and surrounded by water, which, together with the steam room, is contained in an outer shell. The principal varieties of boilers are,—the *cylinder boiler*, which consists of a single iron shell; the *return-flue* and the *drop-flue* boilers, called *flue boilers*, which are single shells containing a small number of large flues, through which the heat either passes from the fire or returns to the chimney, and sometimes containing a fire-box enclosed by water; the *multiflue* or *locomotive boiler*, which consists of an enclosed fire-box and a large number of small flues leading to the chimney; and the *water-tube boiler*, which consists of an enclosed fire-box and a fire-chamber filled with small tubes, through which the water circulates. *Tubular boiler*, *a multiflue* or multitubular boiler, in distinction from a boiler with large flues.

Copper, when the temperature of the steam does not exceed 200° Fahr., is the best material for boiler construction, its power of conducting heat being nearly double that of iron; a copper boiler of only one-half the superficial contents of an iron one will generate a similar quantity of steam. The power of copper in conducting heat is about 898·2, and that of iron 374·3. Iron possesses the greatest cohesive strength, yet manufacturers generally construct their copper boilers of thinner metal on account of the greater uniformity in the substance of copper plates as well as for the sake of economy, copper being five times the cost of iron; but an old worn-out boiler is worth three-fourths its original value, whereas the value of an old iron one is comparatively trifling when the cost of removal is deducted. Copper has also been proved to be the safest: when a copper boiler bursts or explodes it is merely rent open, but an iron boiler is generally blown to pieces.

834.

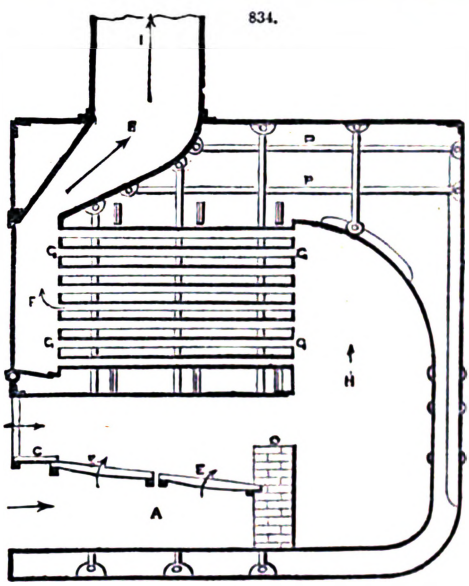


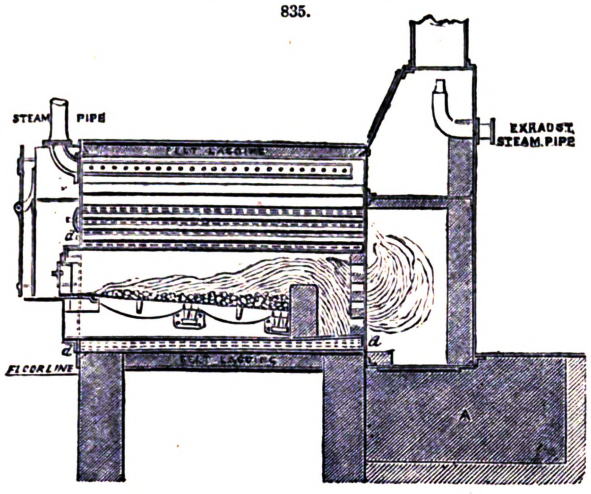

Fig. 834, which is a longitudinal section of a marine tubular boiler, shows the general arrangement of parts in a marine boiler. A is the ash-pit; C dead-plate; E E the grate; F F the uptake; G G the tubes and tube-plates; H the back uptake, flame-chamber, or rising flue; I the chimney; O the bridge; and P P stay-rods.

The boiler shown in Figs. 835, 836, 837, is according to an arrangement invented by David Thomson, and successfully introduced by Richard Moreland and Sons, London.

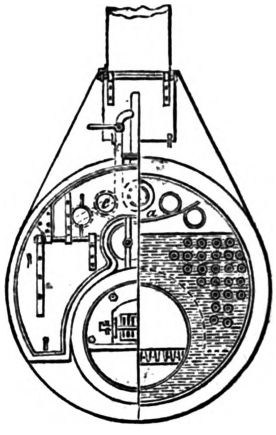
Fig. 835 represents a longitudinal section, and Fig. 836 a front elevation and cross-section of a Thomson boiler, 8 ft. long and 5 ft. 6 in. diameter, having the same amount of heating-surface as an ordinary Cornish boiler 27 ft. long and 5 ft. diameter, with an internal fire-tube 2 ft. 9 in. diameter. Fig. 837 is a front elevation and cross-section of a boiler, 8 ft. long and 8 ft. diameter, having as much heating-surface as the very largest sized double-flued Cornish boiler 33 ft. long and 7 ft. diameter. The fire-chamber is the same as in Cornish boilers, and is fitted with the usual furnace door and adjustable slide to admit air over the fire for the combustion of the smoke. The ash-pit is also fitted with a door,

by means of which the draught can be regulated. The products of combustion, after passing the fire-bridge, make their way through perforated fire-brick into a roomy chamber lined with fire-brick, and thence pass through the small tubes to the front smoke-box, from which they return

835.

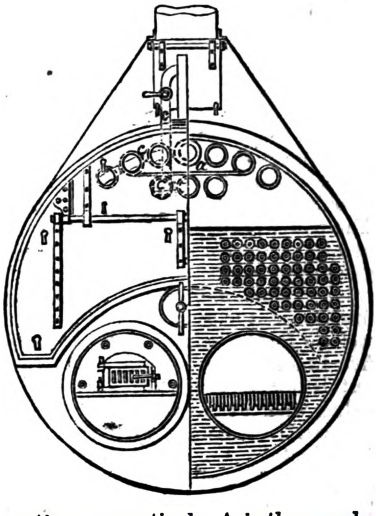



836.




through the larger tubes to the chimney, superheating and drying the steam in their passage. The steam-pipe extends internally over the whole length of the boiler, and is pierced with small holes, which cause it to take the steam equally from all parts of the boiler, while the steam is compelled by the plate *a*, Figs. 835 to 837, to pass over the heated surface of *all* the large tubes before reaching the steam-pipe. Ogle, of whom we shall hereafter speak, introduced this description of steam-pipe in some of the later arrangements of his boiler. When the boiler is used for non-condensing engines, it is advisable to bring the exhaust-pipe of the engine to the bottom of the chimney, as at *b*, Fig. 835, where it serves to stimulate the draught. But provision is made for increasing or regulating the draught to any extent by a steam-jet pipe *c*, Figs. 836, 837, having a small hole opposite the centre of each of the large tubes, by which a jet of steam can be projected through it. This method of applying the steam jet to increase the draught is found to be much more certain, powerful, and economical than when applied in the chimney.

837.



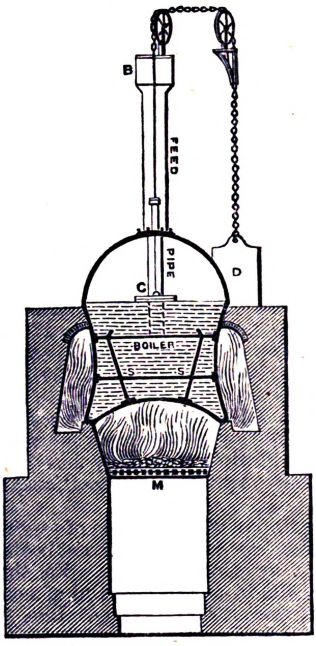

This boiler, constructed by the Morelands, is short and of large proportional diameter, and from its circular form is well adapted for high pressures. There is also a large amount of heating-surface within a small bulk, and no boiler-seating is required; hence it is a boiler suitable for situations where space is limited, or when it is desirable to reduce the cost of fixing and of brickwork.

The wagon-boiler, Figs. 838, 839, is used for generating low-pressure steam only.

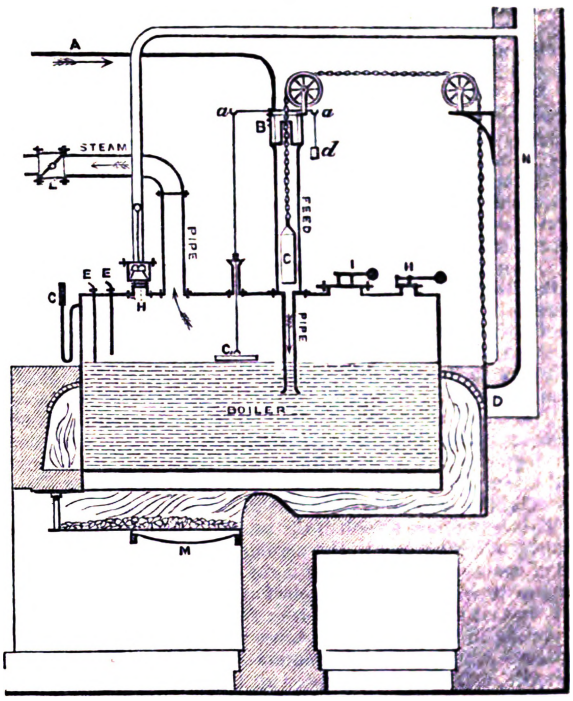
In Figs. 838, 839, which are transverse and longitudinal sections respectively, A is the supply-pipe from the hot well terminating in the cistern at the top of the feed-pipe; B cistern at the top of feed-pipe, having a valve fixed at the bottom; C the float employed to regulate supply of water to boiler. The water is kept at the same height by its action upon the valve at the bottom of the feed-pipe; thus, when there is not sufficient water in the boiler, the float sinks, pulls down the arm of the lever *a a* to which it is attached, and opens the valve, since the counterbalancing weight *d* fixed at the other end of the lever will only support the float when in its proper situation in the boiler and at the required level of the water. D is a self-acting damper for regulating the consumption of fuel; E E gauge-cocks; G steam-gauge; H safety-valve, regulated by the engineer; I air-valve, or atmospheric safety-valve; U the locked safety-valve. A pipe is shown at the top which leads the steam that escapes into it to the flue or into the air. The steam passes from the boiler through the steam-pipe; a valve, called a throttle-valve, L, being placed in it for regulating the amount of steam to the cylinder; M furnace-bars; N the flue; S, S stays.

Figs. 840 and 841 represent longitudinal and transverse sections respectively of the Whittle boiler. *a*, *a* are the plates forming the body of the boiler; *b*, *b* the inner casing or lining; *c* is the circulating space between the inside of the boiler and casing, *b*. When heat is applied to the outside of the boiler *a*, the water in the space *c* is first heated, and commences to ascend in the space *c*; and as the heat increases, a rapid circulation of the water and steam takes place up the heated sides of the boiler. When the water and steam reach the upper edge or lip of the casing *b* (which extends a little above the water-level), the steam is separated from the water, which steam occupies the upper part of the boiler; but the water boiling over the edge of the lining or casing *b* into the central part of the boiler, descends through the short upright pipes *d d* through the bottom of

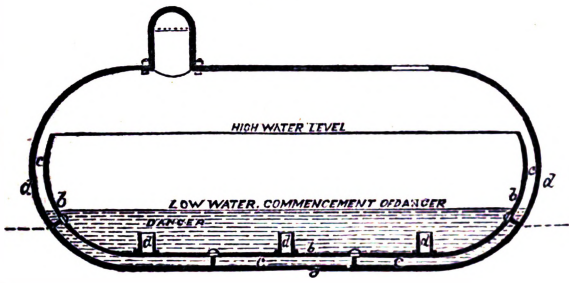
838.



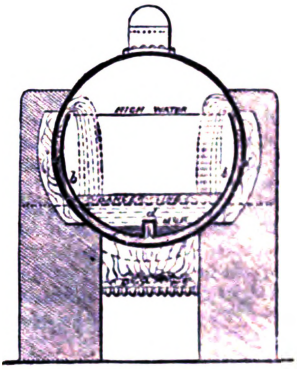

839.



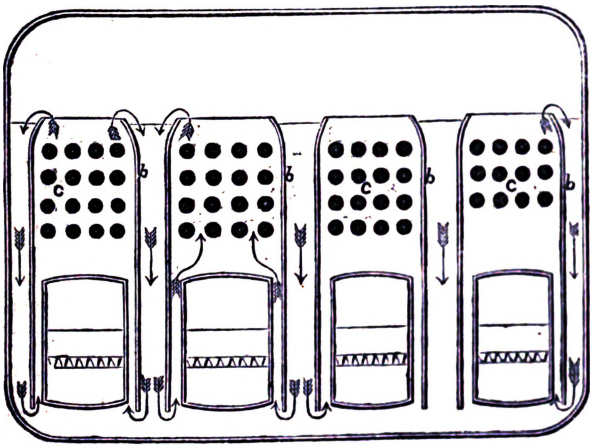

840.



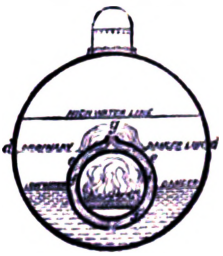

841.




843.




842.



the lining into the space *c*, and thus maintains a continuous circulation so long as heat is applied. The mud carried over settles on the bottom of the lining, as shown in the figures, where it is retained, thus preventing the formation of deposit on the plate of the boiler. By this arrangement, the boiler is kept clean and not liable to rapid incrustation. When Cornish or fluid boilers are used, as shown in Fig. 842, the flues are surrounded by a casing *e e*, the circulation taking place up the space *f f*, the hot water and steam being delivered at the opening *g*, as shown in the drawing.

Fig. 843 represents the application to a marine steam-boiler, where *b b* are the linings or diaphragms between the series of flues *c c* of the boiler. By the use of these linings or diaphragms *b* a steady circulation of the water in the boiler is set up, and the mud and deposit are, in consequence, made to accumulate at the bottom of the boiler, from whence it may be blown off.

Before giving an extensive analysis of the different arrangements of locomotive, marine, and other boilers, designed to effect particular objects, it is necessary to point out some of the leading properties of heat, water, and steam, determined by abstract reasoning and corroborated by experiment.

Calorific Capacity of Bodies. *Unity of Heat.*—In observing the general mode in which bodies become heated, we recognize this fact, which may be said to be purely external, that in order to bring different quantities of a same substance to a same temperature, the same combustible being used, the weights of the latter must be proportional to those of the substance.

For example, if 10 kilogrammes of coal are requisite to raise the temperature of a certain weight of water from 0 to 20 degrees—the conditions remaining unaltered—it will take 20 kilogrammes to perform the same operation upon twice that weight of liquid.

The reduction of this observation to the accurate data of science led to the following positive result, namely: That, to raise a same weight of a same homogeneous and determinate substance one degree in temperature, the expenditure of a same quantity of heat is invariably necessary. And moreover, with certain restrictions: That the quantities of heat required are proportional to the weight of that same body and to the increase of temperature.

This being once established, it became easy to create a representative value capable of serving as unity of comparison in the various interchanges of heat that take place between different bodies, and of enabling us, also, to estimate the quantities of heat supplied by calorific sources. For that purpose it was sufficient to select some homogeneous substance, and to adapt, as point of comparison, that exact amount of heat that was required to raise its temperature by a given value.

Acting in accordance with these principles, that quantity of heat which is necessary to increase the temperature of one kilogramme of water by one degree centigrade is what has been adopted as the unity, and serves to compare all the interchanges of heat that are observed.

Consequently, if we take a kilogramme of water at zero, and raise it to the temperature of one degree, we say we have given it one unit of caloric; if to two degrees, two units; and so on. In like manner, one kilogramme of water, at any temperature above zero, is considered to possess as many units of caloric as it has degrees of temperature.

We are here speaking of water in its liquid state, and of its heat in so far as it is sensible to the thermometer, but not of the total amount of heat it in reality possesses at a given temperature. We shall hereafter see that the greater part of the heat contained in a body is *latent* and constitutive of its liquid or gaseous state.

Let us, as an example, suppose a red-hot bullet to be plunged into a vessel of water, and then observe the increased temperature derived by the latter from the cooling of the bullet, as it abandons its heat in favour of the liquid. By taking into consideration the water only, and setting aside the losses of caloric occasioned by evaporation and radiation, it will be easy to estimate the amount of heat gained by the liquid mass, by means of its actual weight and increased temperature.

From what has just been said of the connection that exists between the temperatures in degrees and the quantities of heat, if 50 kilogrammes of water, at the temperature of 12 degrees, acquire a temperature of 45 degrees by the immersion of a heated body, the quantity of caloric gained by the water will be ascertained by finding the product of the difference of the observed temperatures by the weight of the mass expressed in kilogrammes.

Let W be the weight of water in kilogrammes;
$t$ be the original temperature;
$t'$ be the increased temperature;
$n$ be the number of units of caloric gained;

we have

$$n = (t' - t)\,\mathrm{W};\ \text{whence}\ n = (45 - 12)\ 50\ \text{kilos.} = 1650\ \text{units.}$$

The reasoning would be precisely the same if it were required to find the number of units of caloric lost by the immersion of a body colder than the water.

If, for example, we plunge a very cold body into 50 kilogrammes of water at 45 degrees, and that, the temperature being thereby reduced to 10 degrees, we wish to know how many units of caloric have been lost by the water after the equilibrium has been restored, we have, as before,

$$n = (45 - 10)\ 50 = 1750\ \text{units.}$$

*Specific Heat.*—A body is said to have a greater or less capacity for heat, according as it requires a greater or less amount to cause its temperature to vary an equal number of degrees. If, by comparing two equal weights of two different substances, it be found that, in order to increase their respective temperatures by one degree, it takes twice the quantity of heat in the one case that it does in the other, we conclude that the calorific capacity of the one mass is double that of the other. By representing, therefore, the smaller capacity by 1, we may represent the larger by 2.

The calorific capacity may likewise be characterized by observing the ratio of the temperatures acquired by equal masses of different substances to which equal quantities of heat have been communicated. the coldest evincing, necessarily, the greatest calorific capacity. Moreover, the

numerical ratios of those capacities will be represented by the temperatures expressed in degrees, but in inverse proportion.

For instance, supposing that we plunge three equal bullets, of the same metal, and heated to the same temperature, into three equal volumes of different liquids, and afterwards find that the temperatures of those liquid masses have been respectively raised 1 degree, 2 degrees, 3 degrees; it may be said that their calorific capacities are inversely proportional to these increments of temperature, that is, as 3 : 2 : 1.

So that the calorific capacity of a body, or its *specific heat*, is represented by a number, similar to a coefficient, and which has reference to the unity for which the specific heat of a certain substance serves as standard.

For liquids and solids the standard chosen is water, the unity of heat corresponding, as we have already stated, to that quantity which is necessary to raise the temperature of 1 kilogramme of water 1 degree.

In the case of gases, atmospheric air has been selected as the standard of comparison; but water must, nevertheless, also be used, so that absolute practical values may be obtained.

When we wish to find the respective calorific capacities of gases, we compare them, one with another, in equal volumes, but under two different conditions.

When a gas is heated, it expands, and tends to increase its volume. If it be subject to a constant pressure, that augmentation takes place freely, according to the value of its coefficient of expansion. If, on the contrary, the space that it occupies be inextensible, its volume remains the same, but its pressure increases. It has, consequently, been the preoccupation of physicists to ascertain whether, under these two conditions, the calorific capacities of gases might not be different; and that is why the Tables, giving the results of their labours, show two columns, based upon the foregoing consideration.

From the purely practical point of view we are now taking of the subject, this distinction is, perhaps, not of any very great importance, especially as the differences themselves are not very considerable; but it was necessary that we should mention it, in order that the following Tables, borrowed from the illustrious *savants* to whom we are indebted for these useful researches, may be better understood.

We must further state that it is our intention to cite such substances only as are susceptible of being employed in the organs of motion about to occupy our attention.

To render these Tables perfectly intelligible, it will be sufficient if we define clearly what is meant by the numerical value of the coefficient of specific heat, or simply, by the calorific capacity of a body.

It being agreed to term *unity of heat* that quantity of caloric which increases by 1 degree the temperature of 1 kilogramme of water, comparisons were made with a large number of substances, and it was found that that same amount of heat produced, in every kilogramme, modifications of temperature that differed widely, according to the substance to which it was applied; and that, in nearly all cases, the elevation of temperature was much more considerable than that of the water.

But this very definition of calorific capacity tends to show that the ratio between the increased temperature of the water, that is to say, one degree or unit for every kilogramme, and the increase of temperature of the substance under consideration, is precisely equal to the inverse ratio of the capacities of that substance and the water.

Consequently, if $c$ represent the capacity of water and $t$ its increased temperature, $c'$ the capacity of the substance to be compared and $t'$ its increased temperature, we shall have

$$t : t' :: c' : c, \text{ or } \frac{t}{t'} = \frac{c'}{c}.$$

But the value of both $t$ and $c$ being the unity, the capacity $c'$ of the given substance is

$$c' = \frac{1}{t'}.$$

Whence we derive the following definition:

*The numerical value $c'$ of the coefficient of specific heat of a determinate substance is equal to the quotient of the unity divided by the increase of temperature produced by one unit upon one kilogramme of that substance.*

The values inscribed in the following Tables are precisely the aforesaid quotients for each corresponding substance. A little later we shall give a few examples of the use of these values.

TABLE I.—CAPACITIES OF GASES.

Ascertained by MM. Delaroche and Bérard, those of air and water being taken as unity.

| Names of Gases. | Calorific Capacities, that of Air being 1 for | | Capacities for equal Masses, Water being taken as unity. | Ratio of Capacities for | |
|---|---|---|---|---|---|
| | Equal Volumes. | Equal Masses. | | Constant Volumes. | Constant Pressures. |
| Atmospheric air .. .. | 1·000 | 1·000 | 0·2669 | 1·421 | 1·00 |
| Hydrogen .. .. .. | 0·9035 | 12·3401 | 3·2936 | 1·407 | 1·00 |
| Oxygen .. .. .. .. | 0·9765 | 0·8848 | 0·2361 | 1·415 | 1·00 |
| Steam .. .. .. .. | 1·9600 | 3·1360 | 0·8470 | According to Dulong | |

By this Table it is seen that, weight for weight, hydrogen is the most difficult gas to heat, since it requires twelve times more caloric than atmospheric air to raise it to an equal temperature.

After hydrogen comes steam, whose capacity is almost double that of air, and very nearly equivalent to that of water.

The two last columns of the Table indicate, according to Dulong, the variations undergone by the calorific capacities of the corresponding gases, whether they be considered under constant volumes or constant pressures while submitted to the influence of heat. We see that, the pressure being constant, the capacity varies from 1 to about 1·4, if the gas is compressed by the effort of expansion that takes place during heating.

However, this question is far too complicated for us to give it full extension here; we have thought proper, therefore, merely to mention it by the way, referring those of our readers who are desirous of more deeply investigating it to special works upon the subject.

TABLE II.—CALORIFIC CAPACITIES OF VARIOUS SUBSTANCES.

That of water being taken as unity.

| Names of Substances. | Calorific Capacities. | Observations. |
|---|---|---|
| Water | 1·0000 | |
| Iron | 0·1100 | Dulong and Petit. |
| „ from 0° to 100° | 0·1098 | „ „ |
| „ „ 0° „ 300° | 0·1218 | „ „ |
| Cast iron | 0·1298 | Regnault. |
| Steel | 0·118 to 0·127 | „ |
| Copper | 0·0949 | Dulong and Petit. |
| „ from 0° to 100° | 0·0940 | „ „ |
| „ „ 0° „ 300° | 0·1013 | „ „ |
| „ | 0·09515 | Regnault. |
| Brass | 0·09391 | „ |
| Lead | 0·0293 | Dulong and Petit. |
| „ | 0·0314 | Regnault. |
| Tin | 0·0514 | Dulong and Petit. |
| „ | 0·05623 | Regnault. |
| Zinc | 0·0927 | Dulong and Petit. |
| „ | 0·09555 | Regnault. |
| Glass from 0° to 100° | 0·1770 | Dulong and Petit. |
| „ | 0·1900 | Dulong and Petit. |
| „ from 0° to 300° | 0·19768 | Regnault. |
| Charcoal | 0·2415 | „ |
| Coal and coke (average) | 0·20 | „ |
| Woods, various | 0·600 to 0·650 | Mayer. |

This second Table, relating to the calorific capacities of the principal substances used in construction and manufactures, shows that, of them all, water possesses the greatest, and is, consequently, the most difficult and the most expensive to heat. The next is wood, and that which has the smallest capacity is lead.

*Application of the Coefficients of Calorific Capacity.*—The knowledge of the calorific capacities of bodies, and their representation by numerical values, lead to problems that are both highly interesting and extremely useful in their application. The principal ones may be summed up as follows:—

1st. Find the quantity of heat necessary to raise the temperature of a body a given number of degrees; and reciprocally, how much heat must be withdrawn in order to lower its temperature in the same proportion.

2nd. Find the temperature of a mixture, whether the bodies be equal or unequal in mass and calorific capacity.

3rd. Find the effects of expansion produced by given quantities of heat upon gases or vapours.

We will endeavour to illustrate by a few examples these different modes of treating the question; reserving, however, for later, further particulars relating to expansion, which may be more particularly interesting when we come to speak of superheated steam and of motors worked by gases.

*Researches as to the Quantity of Heat corresponding to a given Variation of Temperature.*—It has been seen, from the definition of capacity and the unity of heat, that the amount of caloric a body loses or gains, according as it becomes heated or chilled to a given number of degrees, is proportional both to its mass and to its calorific capacity; since, if 1 kilogramme of water absorbs 1 unit in order to gain 1 degree in temperature, it would absorb 2 units for 2 degrees, and so on; or else, 2 kilogrammes would absorb 2 units for 1 degree: finally, 1 kilogramme of a substance whose specific heat is 0·5 would absorb half a unit to raise its temperature 1 degree, and so on. Consequently, the general formula for heating and cooling is this:

$$n = t\,\mathrm{W}\,c, \text{ or } n = (t' - t)\,\mathrm{W}\,c, \qquad [\mathrm{A}]$$

$t' - t$, or simply $t$, being the difference of temperature, or the number of degrees gained or lost.

First example.—How many units of heat would be absorbed by 50 kilogrammes of water at 15 degrees, that its temperature might be increased to 60 degrees?

$$n = (60 - 15) \times 50 \times 1 = 2250 \text{ units.}$$

The result would evidently be the same in order to lower the temperature from 60 degrees to 15 degrees.

Second example.—If 3000 units of heat were supplied to 500 kilogrammes of water, what would be the increase in its temperature?

By the preceding formula we have

$$t = \frac{n}{W\,c}\text{; whence } t = \frac{3000}{500 \times 1} = 6 \text{ degrees.}$$

Third example.—How many units of caloric are given out by 100 kilogrammes of iron when, in cooling, its temperature is lowered 200 degrees?

The preceding Table indicates that the calorific capacity of iron is 0·11, therefore

$$n = 200° \times 100^k \times 0{\cdot}11 = 2200 \text{ units.}$$

Fourth example.—When 100 kilogrammes of a body give out 1000 units of heat in cooling, and its temperature is lowered 55 degrees, what is its calorific capacity?

From the same formula whence we derived the value of $t$, we also obtain

$$c = \frac{n}{t\,W}\text{; or } c = \frac{1000}{55 \times 100} = 0{\cdot}1819.$$

*To Find the Temperature of a Mixture or Compound.*—This problem is susceptible of various solutions, according as the capacities of the substances compounded are equal or different. We will give examples of both cases. It is possible, however, to establish a general formula, that will only be simplified if the masses or capacities are equal.

If two substances be compounded whose weights are W and W', the temperatures $t$ and $t'$, and the capacities $c$ and $c'$, there will result a final temperature $x$, to find which we reason thus:

After mixing, the two masses will have acquired an even temperature; the one will be a certain number of degrees colder, represented by $t - x$, whence the number of units it will have lost will be $= (t - x)\,W\,c$; while the other, on the contrary, will have acquired an accession of caloric $(x - t')\,W'\,c'$.

But since that which was lost by one of the masses has been gained by the other, these two quantities are equal, and give the following equation:

$$(t - x)\,W\,c = (x - t')\,W'\,c', \qquad [B]$$

from which we obtain

$$x = \frac{t\,W\,c + t'\,W'\,c'}{W\,c + W'\,c'}, \qquad [C]$$

$x$ being the required temperature of the compound.

It is evident, however, that when the masses or the capacities are equal, the symbols whereby they are represented must be eliminated from the foregoing expression. For instance, if the masses of the bodies compounded were equal, we should have W = W'; and the relation would assume the following form: $\frac{t\,W\,c + t'\,W\,c'}{W\,c + W\,c'}$; whence we have $\frac{(t\,c + t'\,c')\,W}{(c + c')\,W}$, where W necessarily disappears, leaving

$$x = \frac{t\,c + t'\,c'}{c + c'}, \qquad [D]$$

that is to say, the mass is not to be considered.

If the capacities were equal, the same operation would be performed with respect to $c$ and $c'$ which would disappear, the formula taking the shape

$$x = \frac{t\,W + t'\,W'}{W + W'}. \qquad [E]$$

Finally, if the masses and the capacities both happened to be equal, one expression would then be reduced to the following:

$$x = \frac{t + t'}{2}. \qquad [F]$$

It will be seen that the foregoing first general expression [B] suffices to find the temperature of a compound under every condition. We may even suppose the form reversed, and that it be proposed to find the requisite proportions of a compound in order to obtain a given temperature. We will give a few examples of each particular case.

First example. Equal masses and equal capacities.—Find the temperature $x$ of a mixture of two equal masses of water, the one at a temperature $t = 25$ degrees, the other at a temperature $t' = 40$ degrees.

Formula [F] $$x = \frac{t + t'}{2} = \frac{25° + 40°}{2} = 32{\cdot}5 \text{ degrees.}$$

Second example. Equal capacities.—What will be the temperature of a mixture of 10 kilogrammes of water at 12 degrees and 15 kilogrammes at 50 degrees?

Formula [E]:

$$x = \frac{t\,W + t'\,W'}{W + W'} = \frac{(12° \times 10) + (50° \times 15)}{10 + 15} = 34{\cdot}8 \text{ degrees.}$$

Third example. Equal masses.—500 kilogrammes of water at 90 degrees are poured into a copper vessel of the same weight and a temperature of 15 degrees; find the temperature of both vessel and water, at the moment of equilibrium, supposing that there are no losses of caloric.

Formula [D]. By the Table we find the capacity of copper to be 0·095. Consequently, we have

$$x = \frac{t\,c + t'\,c'}{c + c'} = \frac{(90° \times 1) + (15° \times 0{\cdot}095)}{1 + 0{\cdot}095} = 83{\cdot}5 \text{ degrees.}$$

So that the temperature has only fallen 6°·5, to raise that of the 500 kilogrammes of copper from 15° to 83°·5: this is owing to the enormous difference between the capacity of water and that of copper.

Fourth example. All conditions differing.—A mass of iron weighing 150 kilogrammes, and at a temperature of 300 degrees, is plunged into 100 kilogrammes of water at 10 degrees; what will be the temperature of the water when equilibrium of temperature has been established?

The different data of the problem stand thus:

| | | |
|---|---|---|
| Capacities .. .. | Water .. .. .. .. .. .. | $c = 1$ |
| | Iron .. .. .. .. .. .. | $c' = 0{\cdot}11$ |
| Temperatures .. | Water .. .. .. .. .. .. | $t = 10°$ |
| | Iron .. .. .. .. .. .. | $t' = 300°$ |
| Weights .. .. | Water .. .. .. .. .. .. | $W = 100^k$ |
| | Iron .. .. .. .. .. .. | $W' = 150^k$ |

Formula [C]:

$$x = \frac{t\,W\,c + t'\,W'\,c'}{W\,c + W'\,c'} = \frac{(10° \times 100^k \times 1) + (300° \times 150^k \times 0{\cdot}11)}{(100^k \times 1) + (150^k \times 0{\cdot}11)} = 51{\cdot}07 \text{ degrees.}$$

Fifth example. Mixture of gases.—The preceding rules apply equally to the mixtures of bodies whose quantities are expressed by their volumes. Thus it has been already seen that the relative capacities of gases have been ascertained in this manner, by taking atmospheric air as the unity.

We propose, therefore, to find the temperature $x$ of a mixture of two volumes of hydrogen and oxygen under the following conditions:

| | | |
|---|---|---|
| Capacities .. .. | Hydrogen .. .. .. .. .. .. | $c = 0{\cdot}9035$ |
| | Oxygen .. .. .. .. .. .. | $c' = 0{\cdot}9765$ |
| Temperatures .. | Hydrogen .. .. .. .. .. .. | $t = 10°$ |
| | Oxygen .. .. .. .. .. .. | $t' = 45°$ |
| Volumes .. .. | Hydrogen .. .. .. .. .. .. | $V = 1^{mc}$ |
| | Oxygen .. .. .. .. .. .. | $V' = 0^{mc}{\cdot}800$ |

Formula [C]:

$$x = \frac{V\,t\,c + V'\,t'\,c'}{c\,V + c'\,V'} = \frac{(1^{mc} \times 10° \times 0{\cdot}9035) + (0^{mc}{\cdot}800 \times 45° \times 0{\cdot}9765)}{(0{\cdot}9035 \times 1) + (0{\cdot}9765 \times 0{\cdot}800)} = 26°{\cdot}2.$$

*To Find the Proportions of a Mixture.*—It is as frequently required, in practice, to ascertain in what proportion a mixture ought to be compounded so as to have a certain temperature, as it is to perform the inverse operation: and, although the only thing necessary for that purpose is a suitable adaptation of formula [B] or [C], involving no difficulty, we will, nevertheless, give a few more examples.

First example.—Given a mass of lead weighing 75 kilogrammes, at 150 degrees, in what body of water at 12 degrees should it be plunged in order that the whole exceed not 20 degrees at the moment that the equilibrium of temperature is established between the liquid and the metal?

The unknown quantity, this time, is the weight W of the mass of water; and, if we retain the same notation as in formula [B], $x$, the temperature of the mixture, will equal 20 degrees. Consequently, the fundamental formula [B] being $(t - x)\,W\,c = (x - t')\,W'\,c'$, we easily extract from it the value $W = \frac{(x - t')\,W'\,c'}{(t - x)\,c}$, which becomes the general expression applicable to all problems of the nature of the one above proposed, and of which we will now give the solution. It must be observed, however, that in this particular case, where $t'$ is greater than $x$, and $x$ is greater than $t$, it would be as well to transpose the complex quantities between brackets in order not to have negative values, which should, nevertheless, not affect the result: on the other hand, as $x$ is no longer the unknown quantity, we shall replace it by the sign T, to indicate the given temperature of the mixture.

The foregoing expression, thus modified, then becomes

$$W = \frac{(t' - T)\,W'\,c'}{(T - t)\,c}, \qquad [G]$$

and if we introduce into this formula the several data of the problems, together with the calorific capacity of lead = 0·0293 (second Table), we find that the body of water required is

$$W = \frac{(150° - 20°)\,75 \times 0{\cdot}0293}{(20° - 12°) \times 1} = 35{\cdot}709 \text{ kilogrammes.}$$

The relative smallness of this weight of water is perfectly in accordance with the small calorific capacity of lead, which is about the three-hundredths of that of water.

Second example.—What weight W of cold water, at $t = 12$ degrees, must be added to W', = 100 kilogrammes of the same liquid, at $t' = 80$ degrees, so as to obtain a mixture T, = 20 degrees?

As here the capacity is the same for both masses, the formula [G] becomes

$$W = \frac{(t' - T)\,W'}{(T - t)}; \text{ whence } W = \frac{(80 - 20) \times 100}{20 - 12} = 750 \text{ kilogrammes.}$$

These examples will be sufficient to show the utility and the application of the coefficient of specific heat; they, moreover, lead up to the solution of those problems involving quantities of *latent heat*, touching which we are now going to speak. It must, however, be stated that the experiments that have enabled the determination of the calorific capacities of the different bodies

correspond only with a limited range of temperature, beyond which those capacities may be found to vary slightly. But, in practice, this uncertainty has no material importance, especially as bodies that are subjected to heat invariably lose, from accidental causes, quantities thereof considerably greater than could possibly arise from the incorrectness of the coefficients.

*Latent Heat.*—At the moment any change takes place in a body, whether it be its transition from the solid to the liquid state, or from this last to that of gas, a very curious and remarkable calorific phenomenon is observed. It is found that its temperature remains the same so long as the change in its state is going on, and consequently, that the quantities of heat with which it is supplied in the meanwhile are not perceptible by the thermometer.

This peculiarity is thus explained: while a body is changing its state, it absorbs a certain amount of heat which is exclusively employed in bringing about that change, but does not in any way tend to modify the temperature of the body. Hence the term *latent* given to that quantity of heat, which effectually is *hidden*, since it cannot be detected by the instrument generally used to reveal its presence. Latent heat was discovered, compared, and measured by Dr. Black.

In like manner, if either of the above-mentioned changes takes place inversely in a body—that is to say, if from the state of gas it passes to that of liquid, or from the state of liquid to that of solid—it will be observed to give out a certain quantity of heat without its temperature being in the least affected thereby while the operation is going on. This is nothing more than its abandonment of that *latent heat* which was necessary to maintain it in its recent state.

*Fusion Heat.*—The first example to be cited in demonstration of the existence of latent heat, is the transformation of water into ice, or, reciprocally, its return from the solid to the liquid state. Long before the experiments, which we will term *quantitative*, were made, it was known that there existed solid water (ice) as well as liquid water at zero, although it was necessary to heat the ice to cause it to melt. That already sufficed to reveal the existence of a certain amount of caloric absorbed solely by this change of condition; but its great importance had yet to be discovered. It was then shown, after very minute researches, that if 1 kilogramme of ice at zero be brought into contact with 1 kilogramme of water at 79°, there will remain, after the fusion is completed, 2 kilogrammes of water at the temperature of zero. Consequently, the whole of the manifest heat contained in the 1 kilogramme of liquid water is absorbed in reducing the 1 kilogramme of ice to a similar state; and, while the temperature of the latter remains unaltered, that of the former falls from 79 degrees to zero. The result would be the same if, instead of 1 kilogramme at 79°, we took 79 kilogrammes at 1°.

By referring to what has been said about calorific capacity, we perceive that the one kilogramme of water at 79° represented the same number of units of heat as were actually employed in melting the one kilogramme of ice; whence we conclude (see the experiments of MM. de la Provostaye and Desains) that

*One kilogramme of ice, at the temperature of zero, will absorb* 79 *units of heat, called latent, or, more strictly,* 79·25 *units, in order to pass into the liquid state:* that

*One kilogramme of water, at no matter what temperature, contains, above zero, as many units of caloric as it does degrees of temperature, plus* 79·25.

This phenomenon of latent fusion heat is common to all bodies which possess each their peculiar quantity of caloric absorbed for each unit of weight.

As, in steam-engines, water intervenes solely under its second change of state, we will not dwell any longer upon the first—though we deemed it indispensable that it should be known, but will close this part of the subject by a few examples.

First example of the latent fusion heat of ice.—We propose to find the quantity of water necessary to melt a certain weight of ice at the assumed temperature of zero, which shall also be the temperature of the mixture after the fusion has taken place. Let the

| | |
|---|---|
| Weight of the ice be .. .. .. .. .. .. | $W = 25$ kilogrammes. |
| Weight of the water be .. .. .. .. .. | $W' =$ unknown. |
| Temperature of the water be .. .. .. .. | $t = 15$ degrees. |
| Fusion heat be .. .. .. .. .. .. .. .. | $l = 79{\cdot}25$ units. |

Solution.—On the one hand, it takes as many times 79·25 units as there are kilogrammes of ice; and on the other, that number of units is equal to the product of the weight of the water required by its temperature, that is to say, $W\,l = W'\,t$. Therefore we have

$$25 \times 79{\cdot}25 = W' \times 15°;\ \text{whence}\ W' = \frac{25 \times 79{\cdot}25}{15} = 132{\cdot}08\ \text{kilos.}$$

Second example.—If $W = 10$ kilogrammes of ice at zero be thrown into $W' = 100$ kilogrammes of water at 18°, what will be the temperature $x$ of the mixture after fusion?

Solution.—It will require 10 times to melt the ice, which will have to be subtracted from the manifest quantities of heat contained in the water, or, 100 times 18 degrees; and the required temperature $x$ is the quotient of that difference divided by the sum of the weights W and W'. Thus,

$$x = \frac{(t\,W') - (l\,W)}{W' + W} = \frac{(18° \times 100) - (10 \times 79{\cdot}25)}{100 + 10} = 9{\cdot}16\ \text{degrees.}$$

We may here remark that it is easy to calculate the total amount of heat $n$ that would be given out by this liquid mass in passing into the solid state at the temperature of zero. We should then have

$$n = (W + W')\,l + (W + W')\,x;\ \text{or,}\ (W + W') \times (l + x);$$

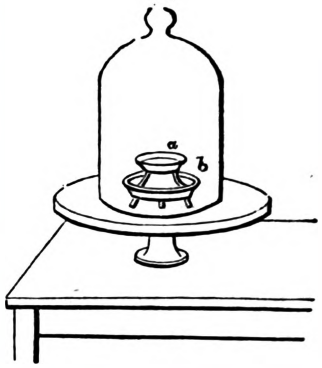
$$\text{whence}\quad n = (10 + 100) \times (79{\cdot}25 + 18°) = 10697{\cdot}5\ \text{units.}$$

And, *vice versâ*, this same quantity of heat would be capable of increasing by one degree the temperature of 10697·5 kilogrammes of water.

*Latent Heat of Steam.*—During the second change of state to which bodies are liable, the effects are precisely identical with the above. When a liquid is transformed into steam it absorbs a very large amount of heat which is entirely undistinguishable by the thermometer, the steam having exactly the same temperature as the liquid whence it emanates. The difference that exists between the effects of fusion and evaporation is this, that, weight for weight, the quantities of latent heat absorbed are much more considerable in the latter case. But both possess this one peculiarity, that the absorption of latent heat takes place whatever may be the process of fusion or evaporation—whether slow or rapid. Thus, any vapour arising from simple ordinary evaporation in the open air possesses just the same quantity of latent heat as that arising from the ebullition of a body of liquid, subject to the same ambient pressure.

When steam is formed from a mass of liquid exposed to the action of a fire, it takes its latent heat from that liquid, which consequently ceases to increase in temperature. But, if this steam emanate from a liquid apart from any active source of heat, its latent heat is taken, not only from the liquid, but also from the vessel containing it and from the surrounding objects. There may thence result a very sensible cooling of those objects and of the said liquid, if the evaporation can be continued without recuperation of heat. Notwithstanding our desire to avoid purely physical disquisitions, we cannot refrain from citing an experiment that brings clearly to light this phenomenon of the absorption of latent heat by evaporation, no matter what the accompanying circumstances may be or the temperature at which it takes place.

844.




A cup of water, at the ordinary temperature, is made to stand over a saucer or pan containing concentrated sulphuric acid, and, the whole being placed under the receiver of an air-pump, as seen Fig. 844, we begin to exhaust the air. By degrees, as the vacuum is established and the pressure under the receiver diminishes, the water begins to boil, and evaporates the more rapidly as the action of the machine is accelerated. But the vapour thus formed, and which would soon arrest all further evaporation if allowed to remain under the receiver, is partly taken up by the machine while the remainder is absorbed by the sulphuric acid; consequently, the vacuum is maintained under the receiver and the evaporation continues. But, in a few moments, the water that remains in the cup will be completely congealed, forming one solid lump of ice.

This curious phenomenon is solely explained by the definition we have just expounded of latent heat. The steam, in forming, has borrowed so much caloric from the water as to lower the temperature of the latter to freezing-point. It now remains for us to give the value of this latent heat of steam, whose outward effects are made visible by means of very simple experiments.

Amongst other experimentalists of merit, the learned M. Regnault made very minute researches touching the latent heat of steam, the general result of which will be found embodied in the following Table:—

TABLE OF THE QUANTITIES OF LATENT HEAT FOR STEAM FORMED BETWEEN 0° AND 230°.

| Temperatures. | Latent Heats. | Temperatures. | Latent Heats. | Temperatures. | Latent Heats. | Temperatures. | Latent Heats. |
|---|---|---|---|---|---|---|---|
| 0 | 607 | 60 | 565 | 120 | 522 | 180 | 479 |
| 10 | 600 | 70 | 558 | 130 | 515 | 190 | 472 |
| 20 | 593 | 80 | 551 | 140 | 508 | 200 | 464 |
| 30 | 586 | 90 | 544 | 150 | 501 | 210 | 457 |
| 40 | 579 | 100 | 537 | 160 | 494 | 220 | 449 |
| 50 | 572 | 110 | 529 | 170 | 486 | 230 | 442 |

The values that appear under the head of *latent heats* indicate the number of units of caloric absorbed by each kilogramme of steam, at the corresponding temperature, at the moment of its formation. Consequently, those same quantities of caloric would be given out by the steam on its return to the liquid state.

For a long time it had been admitted that the amount of latent heat was always the same, no matter at what temperature steam was generated; but the result of M. Regnault's researches shows that notion to be incorrect, and that the quantity of caloric that is absorbed by evaporation diminishes according to a certain progression which is in inverse ratio to the temperatures.

To select the most ordinary examples, let it be observed that whereas water at 100 degrees takes up 537 units of latent heat, that at 150 degrees only absorbs 501 units.

*Application of the Latent Heat of Steam.*—The general study of heat, in its reference to the formation of steam for mechanical purposes, is of twofold importance; firstly, as regards the quantities of fuel to be expended; secondly, as regards the condensation of that same steam after it has done its work. We will give examples of both cases.

First example.—What will be the total number $n$ of units of caloric required by a weight $W = 25$ kilogrammes of water, whose temperature $t = 10$ degrees, in order to convert it into steam under the pressure of 1 atmosphere?

Solution.—The temperature T, apparent by the thermometer, of steam generated under a pressure of 1 atmosphere, being 100 degrees, the number of units of caloric absorbed by each

kilogramme of water will be $T - t$, plus the latent heat $l$ that corresponds to the temperature $t$, according to the preceding Table. We therefore have for the total number of units

$$n = (T - t + l)\,W;$$

a general expression which gives for the proposed example

$$n = (100° - 10° + 537) \times 25 = 15675 \text{ units.}$$

Second example. Mixture of steam and water.—A certain quantity of steam being brought into contact with a given weight of cold water at a fixed temperature, and sufficient to complete its condensation, find the temperature of the mixture.

Let us take the same quantity of steam as in the foregoing example, added to $W' = 200$ kilogrammes of water, at a temperature $t = 15$ degrees; the steam being represented by $W = 25$ kilogrammes; $T = 100$ degrees; we want the temperature $x$ of the mixture.

Solution.—The total mass, or the weight of the steam added to that of the water, will necessarily contain the sum of the quantities of heat possessed by each; if, then, we divide that sum by the entire mass, we shall have the temperature $x$ demanded. Consequently

$$x = \frac{(T + l)\,W + (t\,W')}{W + W'}; \qquad [I]$$

which is a general expression, from which we obtain, as answer to our problem,

$$x = \frac{(100° + 537) \times 25^k + (15° \times 200^k)}{25^k + 200^k} = 84{\cdot}11 \text{ degrees.}$$

This result already shows that it is necessary, relatively, to use very considerable volumes of water to cause a body of steam to return to the liquid state, and in order that after the condensation the temperature of the water may not be too elevated.

Third example.—Let us reverse the proposition, that is to say, find what quantity of water must be added to a given weight of steam that the resulting mixture may not exceed a certain temperature.

Let $W$ = 15 kilogrammes, the weight of the steam;
$T$ = 150 degrees, its temperature;
$l$ = 501, its latent heat (according to preceding Table);
$W'$ = the weight of water required;
$t$ = 10 degrees, its temperature;
$t'$ = 25 degrees, the temperature of the mixture.

Solution.—By simply bearing in mind that $t'$ takes the place of $x$, it is precisely the above formula [I], in which $W'$ becomes the unknown quantity. Thus, $t'\,W + t'\,W' = (T + l)\,W + t\,W'$; whence

$$W' = \frac{(T + l - t')W}{t' - t}. \qquad [J]$$

This last expression is the one that we shall meet with every time that it is required to ascertain the condensation of a steam-engine; we therefore invite our readers to give it due consideration. As regards our present problem, it gives

$$W' = \frac{(100 + 501 - 25) \times 15}{25° - 10°} = 576 \text{ kilogrammes.}$$

That is to say, putting it in general terms, that in order that the condensation-water shall not exceed 25 degrees of temperature, it will take 576 kilogrammes of cold water at 10 degrees to destroy 25 kilogrammes of steam at 150 degrees. All things being equal, it is, moreover, evident that it will take so much more water to condense steam, that the temperature of the water is higher, and that of the mixture is required to be lower. It is beyond all doubt that, under certain circumstances, it is impossible to achieve the direct condensation of steam in engines and condensing machines for want of a sufficiently large volume of cold water. We shall see by-and-by that, in marine engines, the condensation is often imperfect or entirely suspended, not for want of water, since, in those cases, it is drawn from the sea, but because of the warmth of the water, especially under the tropics.

Here ends, for the present, what we had to say concerning latent heat; its direct application to engines will render sufficiently intelligible all that it is necessary to know upon the subject.

Sources of Heat. *Quantities of Heat supplied by Fuel.*—After the study of the *quantities of heat* required to raise the temperature of bodies and produce a change in their state, we come naturally to that of the *sources of heat* as regards the quantities that they are able to furnish. This forms the entire question of the economy of caloric in its production and its use.

Science teaches us that the combustion of a body is the chemical combination of that body with oxygen, a phenomenon which is accompanied by a great development of light and heat. If considered from this point of view, all bodies would be combustibles, since all possess, more or less, the property of combining with oxygen; but all do not offer, at the moment of entering into combination, such properties as qualify them for fuel, that is to say, a total disengagement of heat greater than that required to produce combustion, that combustion going on even independently of the focus where it takes place; and a cost price of the material itself sufficiently low. But, quitting generalities and basing our arguments upon a few examples, we will observe that wood, coal, hydrogen, and certain other substances burn almost spontaneously, or at least complete entirely their combustion from the moment that one single point of their mass has attained the necessary degree of temperature. Other bodies, such as metals, that combine freely with oxygen, cease burning as soon as they are withdrawn from the focus where the combination is effected; focus

which we are obliged, in consequence, to feed with some other body more readily combustible. Combustible bodies, that is to say, such as are used in manufacture, are not very numerous, and comprise

1. Woods, and vegetable matter generally;
2. Coals, both vegetable and mineral;
3. Peat.

These are the substances into whose composition there enters the greatest amount of carbon and hydrogen, the only two simple bodies which possess, independently, all the requisite properties for the phenomenon of combustion in its application to manufacture, and the quality, therefore, of being excellent combustibles. Animal substances, such as flesh, grease, and bone, are likewise highly combustible; but, on account of the complexity of their composition, the absorption of heat indispensable to the separation of their various elements at the moment of combustion is very considerable, so that a given weight of animal matter does not furnish so large an amount of useful heat as combustibles of a simpler nature. Besides this, there are sufficient uses for animal substances without employing them as fuel, though it has sometimes been done.

Our examination of combustibles can only be very brief, our object being merely to make known what quantities of heat each is able to furnish for every unity of weight.

The estimation of these quantities of heat is entirely based upon the calorific unity already defined. Thus let us suppose a kilogramme of any combustible body to be taken, and that it be found that the heat it has given out during its total combustion has raised the temperature of 2000 kilogrammes of water 1 degree; if the experiment be made with sufficient precision to satisfy us that all the heat thus produced has been absorbed by the water, we then say that the burning of 1 kilogramme of that combustible has supplied 2000 units of heat, for we are aware that that is the standard whereby we should measure the quantity of heat necessary to cause a variation of 1 degree in the temperature of 2000 kilogrammes of water. The amount of heat given out, so measured, takes the name of *calorific power* of the combustible whence it emanates; and very accurate experiments have been made in order to ascertain thus the calorific power of every substance. Those experiments have shown that not only does the said power differ with different bodies, but it also varies considerably in bodies whose composition is susceptible of change. Thus the combustibles used for industrial purposes, being substances of a complex nature, are all possessed of that peculiarity—a variable calorific power. For instance, woods, being of a kind, are essentially different in their composition, setting aside their greater or less degree of desiccation. The several sorts of coal, though variations in their composition are not so great, still show a difference. Even charcoal, one of the purest of all combustible substances, evinces likewise varieties, owing to its more or less perfect preparation.

Such differences should be considered, however, as of a scientific nature, not industrially: that is to say, every combustible possesses a mean calorific power which is all-sufficient for the purpose we propose. The following Table is a summary of the principal substances and their mean power, to which we have added the calorific powers of hydrogen and of bicarbonate of hydrogen or common gas, though these two last are not yet considered as combustibles in an industrial sense.

TABLE OF THE CALORIFIC POWERS OF COMBUSTIBLES USED FOR INDUSTRIAL PURPOSES.

| Names of Combustibles. | Calorific Power expressed in units of Heat given out by the combustion of 1 kilogramme of each Substance. | Authorities. |
|---|---|---|
| Pure hydrogen (the kilo.) .. .. .. .. | 34162 | Favre and Silbermann. |
| „ (the cub. mèt.) .. .. .. | 3067 | „ „ |
| Bicarburetted hydrogen (the kilo.) .. .. | 11857 | „ „ |
| „ „ (the cub. mèt.) .. | 15117 | „ „ |
| Pure carbon .. .. .. .. .. .. .. | 8080 | „ „ |
| Charcoal (mean) .. .. .. .. .. .. | 7000 | Péclet. |
| Wood (very dry) .. .. .. .. .. .. | 3700 | Rumfort. |
| „ (ordinary condition) (mean) .. .. | 2800 | „ |
| Coal (mean) .. .. .. .. .. .. .. | 7000 | Dulong. |
| Coke (to 0·15 of cinders) .. .. .. .. | 6000 | Péclet. |
| Common peat (mean) .. .. .. .. .. | 3600 | „ |
| Purified colza oil .. .. .. .. .. | 9307 | Rumfort. |
| Alcohol, at 42° Beaumé .. .. .. .. .. | 6855 | Dulong. |

The values indicated in this Table represent the maximum of heat for each corresponding combustible; we shall, therefore, term them the *theoretical calorific powers*, of which a certain amount only can be utilized in practice. See FUEL. It must not, however, be taken for granted that these values are entirely exempt from slight errors; the diversity of the results obtained by equally skilful experimentalists proves the contrary; and, besides, it is not probable that, in so complicated a phenomenon as that of the combustion of a body, the figures obtained can be always the same and invariable. But these differences become more manifest when the combustibles are employed for industrial purposes, and seem to banish all hope of our being able to rely on such calorific powers as mathematically correct, since, in those cases, they are neither prepared nor selected with the same care as when used for experiment only. These values, notwithstanding, such as they

are, may be of undeniable service, and this we shall see later. Besides, their degree of approximation is generally more than sufficient for all practical purposes. Fresh experiments, however, would perhaps be necessary and desirable, on account of certain new generators wherein the utilization of fuel appears to be increased in an extraordinary manner, as we shall have occasion to show hereafter.

The figure representing the calorific power of a combustible plays the same part in steam generators as does the measure of the expenditure of water in hydraulic motors; in both cases it is evidently the point upon which the result is based; therefore is it very important that there should exist no uncertainty regarding it.

*Application of Calorific Power.*—Before occupying ourselves with the sources of heat, we first examined the interchanges thereof that take place between different bodies, and then the amount of caloric requisite to increase the temperature of bodies a given quantity or cause their change of state. Having proceeded thus far, we are now prepared to calculate the amount of combustible necessary to be expended for the accomplishment of these operations.

We must, however, make one important remark, namely, that what we seek in the following examples is the *useful* quantities of heat, that is to say, those that are absolutely necessary, regardless of what is lost, and of the excellence of the focus or the disposition of the apparatus.

*Researches respecting the Expenditure of Fuel required to produce a given Increase of Temperature.*—First example.—What would be the useful quantity of charcoal necessary to increase the temperature of 100 kilogrammes of water 10 degrees?

Solution.—Since the preceding notions indicate in what manner we are to ascertain the quantity $n$ of units of heat to be supplied, we very easily find that the weight $w$ of the charcoal, whose calorific power we will call $u$, is $w = \frac{n}{u}$. Granting, according to the preceding Table, that $u = 7000$, the number corresponding to common charcoal, we then have

$$w = \frac{10 \times 100}{7000} = 0^{k} \cdot 142.$$

And that is, effectually, all the weight of coal that ought to be expended if the whole heat produced by the combustible could be absorbed by the water. But even supposing that the vessel that contains the liquid, and the focus, being previously heated, absorb none of the caloric, there would still remain other losses which would increase in a notable manner the above theoretical quantity. For instance, let us imagine the arrangements to be such that 0·6 of the heat are utilized, we should then burn, in reality, $\frac{0 \cdot 142}{0 \cdot 6} = 0^{k} \cdot 237$ of charcoal.

Second example.—What weight of coal must be burnt in order to liquefy 50 kilogrammes of ice at zero, and raise it to a temperature of 100 degrees?

Solution.—The number of units of heat $n$ to be supplied being $(t + l)$ W, we have

$$w = \frac{(100 + 79) \times 50}{7600} = 1^{k} \cdot 177 \text{ of coal.}$$

*Evaporating Power of a given Weight of Combustible.*—What weight of steam at a temperature of 100 degrees would be produced by the useful expenditure of 1 kilogramme of coal, supposing the temperature of the water, before heating, to be 15 degrees?

This is the most important problem of the application of caloric to steam-engines; it is the pivot, as we shall presently see, around which all the improvements therein that have hitherto been conceived, and are still likely to be, revolve.

Solution.—It has already been seen [H] that the number of units of heat necessary to a certain weight of water, in order to convert it into steam, is expressed by $n = (T - t + l)$ W; and as that number of units must be equal to the number given out by the weight $w$ of the proposed fuel, whose calorific power is $u$, we have $w u = (T - t + l)$ W; hence the required weight of steam will be $W = \frac{w u}{T - t + l} = \frac{1^{k} \times 7600}{100 - 15 + 537} = 12^{k} \cdot 21$; which amounts to this, that

1 *kilogramme of coal can,* THEORETICALLY, *evaporate about* 12 *kilogrammes of water, whose temperature, before the application of heat, was* 15 *degrees.*

If we had supposed the steam to be of a higher temperature, the quantity of fuel would likewise have been slightly increased, but only slightly, because the latent heat, which is more considerable, varies but little, and inversely. We will give no further example, as this last will suffice as the basis for all future discussions upon the subject. It is essential, however, that we should make one remark with regard to the above result as compared with those obtained in practice.

Generally speaking, a good generator will evaporate 7 kilogrammes of water; very often it is less; but sometimes it is more, and even, in certain cases, it has almost touched the theoretical figure of 12 kilogrammes, which it seems very difficult to attain, if ever. By the aid of special arrangements, however, and such artifices, for instance, as activating the combustion by means of an additional current of air, and so completing the conversion of the coal into carbonic acid and preventing any particle of matter escaping without being consumed and giving up its contribution of heat, it may be done. This is what is called *consuming the smoke*, which is nothing else, for the most part, but unconsumed, and consequently non-utilized coal. It may be well to remind our readers that the number 7600, which indicates in the preceding Table the number of units of heat for every kilogramme of coal, is a *mean*, and may, consequently, be sometimes exceeded. To establish absolute limits, we will suppose that pure carbon is used, furnishing 8000 units of heat, and we then find that 1 kilogramme of that superior fuel, compared with coal, yet only supplies

$$\frac{12 \cdot 21 \times 8000}{7600} = 12^{k} \cdot 84 \text{ of steam.}$$

We have given no examples of the use of the other combustibles, since in all cases the operation would be evidently identical; it is simply necessary to alter the value of $u$, that is, of the coefficient of calorific power. The only point that it might be interesting to examine is the cost of the unit of heat with each different combustible, and this has been done with much care by Péclet in his excellent 'Treatise on Heat.' But it is to be remarked that the use of such or such a combustible depends much less upon its venal value than upon the greater or less facility with which it can be procured in each locality. Thus, some countries possessing coal and comparatively little wood, like England, France, and Belgium, usually adopt the first as fuel, it being also the one that gives out the most heat as it occupies the least space, and is capable of producing a more intense increase of temperature at the focus. On the other hand, there are services, such as the navy, which will always choose the richest combustible because of the economy of space. But it also sometimes happens that a manufacturing establishment possesses some fuel emanating from its own works, and therefore at its disposal almost free of cost, on which account it uses it without having to inquire whether it is more or less rich than this or that other. Thus it is that we see sawmills feeding their furnaces with sawdust and shavings, tan-yards using their tan, and the sugar-refiners of the colonies the peelings of the dried canes. So that the cost of the unit of heat could only have a real interest in such an event as all the combustibles being equally accessible, a circumstance which, we may safely say, never takes place.

MECHANICAL PROPERTIES OF STEAM. *Conditions relating to the Flow and Expenditure of Steam.*—All that has hitherto been seen regarding steam may be considered as constituting its physical properties, that is to say, those natural phenomena, occasioned by the intervention of heat, which convert a body into a gaseous fluid that may be considered as such, and possessing all the characteristics of permanent gases. Like unto the latter, and fluids in general, steam is susceptible of motions and effects that no longer arise from the mutual actions of the ponderable or imponderable elements of which it is formed, but from the *mechanical efforts* to which it may be subjected or which it is capable itself of producing.

If we adopt water as our standard of comparison, we observe that this liquid, independently of its physical properties, such as density, calorific capacity, and so forth, possesses also the mechanical properties due to the action of gravity, which enable it to be considered under the aspect of its motions, the velocity it can acquire, and the efforts it is able to transmit by yielding to the influence of gravitation and of its own substance. The same thing precisely happens with steam, and gases in general, which can move, acquire velocity, and, finally, exert mechanical efforts by virtue of their expansive force, which here takes the place of simple gravity in a liquid.

We propose, therefore, to examine steam under these several phases, giving to our investigations the title of *pneumodynamics*.

*Flow of Steam through a Narrow-edged Orifice.*—When two vessels, containing gases of unequal pressures, are made to communicate, a flow of gas immediately takes place from the vessel where the pressure is the greatest to that where it is the least; precisely as it would occur if, instead of gases, the two vessels held liquids of different densities or uneven levels, or if one of them were entirely empty.

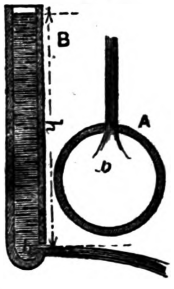
Gases, like liquids, tend towards establishing their equilibrium, then, and in so doing, both follow the same law.

It is shown that the flowing of a fluid through an orifice bored in the side of the vase containing it, and below the free surface, depends, as regards velocity and product, upon two principal conditions—the section of the orifice and the vertical distance between its centre and the surface of the liquid; and that the velocity is expressed by the invariable formula $v = \sqrt{2gh}$ (see HYDRAULICS), where $g$ equals 9·8088, and represents the velocity acquired in one second of time by a body falling in vacuum.

It is also shown that the volume of water flowing, in a given time, is the product of that velocity by the section of the orifice, and by a certain coefficient of contraction.

It is exactly the same with gases, only that the height $h$ of the liquid is replaced by the expansive force of the gas. Consequently setting aside for the present the other conditions of the problem, let us see what the value of $h$ would be in the case of a gas. For this purpose we will suppose that the flow takes place through a narrow-edged orifice which, by its contraction, diminishes the expenditure, but without altering the velocity.

845.




*Velocity with which a Gas flows from a Narrow-edged Orifice.*—Theory and experiment both prove *that the velocity of an* ELASTIC *fluid, flowing in a certain medium and through a narrow-edged orifice, is the same as that which, under similar conditions, would be possessed by a* NON-ELASTIC *fluid of equal density with the gas, but which, by its height of column above the centre of the orifice, would be capable of exerting a relatively equal pressure.*

To render this theorem fully intelligible, let us suppose two vases, A and B, Fig. 845, both standing in the same medium, the atmosphere for instance, the one being filled with a liquid and the other with a gas, under the following conditions:—1st, the gas in the vase A to have a certain pressure; 2nd, the liquid in the vase B *to be of the same density as the gas*, unconfined, and having a height of column $h$ sufficient to press the bottom of the vessel B with an intensity equal to the pressure exerted by the gas against the inner sides of the vessel A.

These conditions being satisfied, if a small orifice $a$ be opened at some point of the vase A, and another $b$ at the lower part of the vase B, the gas and the liquid will both begin to flow, and with the same velocity. This law enables us to work out a first problem which will assist us in establishing the general formula applicable to our present requirements.

Let it be proposed to ascertain with what velocity a second atmospheric air, at a temperature of 0 degrees, would re-enter a perfect vacuum; we have

| | | |
|---|---|---|
| Pressure of air (in cent. of mercury) | P = | $0^{m}\cdot76$ |
| Density „ | $d$ = | 0·001299 |
| „ of mercury | $d$ = | 13·598 |
| Pressure of medium where the flow takes place | $p$ = | 0·0 |
| Velocity of flow in a second of time | $v$ = | $\sqrt{2gh}$. |

It will be seen, in accordance with the preceding theorem, that there only remains to ascertain $h$ to complete the solution of the problem. Moreover, we know that that height must be equivalent to a column of liquid of the same density as air, and exerting the same pressure at its base, that pressure being equal to the difference of pressures between the gas and the medium where the flow takes place, or $P - p$. But here $p$ being a vacuum, and consequently equivalent to zero, the pressure $P - p$ is exactly equal to P, and corresponds with a column of mercury of $0^{m}\cdot76$: the height of the column of non-elastic fluid that would balance it is, therefore, in the inverse ratio of the densities of the fluid and the mercury; that is to say,

$$h = P\frac{d'}{d} = 0^{m}\cdot76 \times \frac{13\cdot598}{0\cdot001299} = 7955\cdot7 \text{ mètres.}$$

It would therefore take a column of fluid 7955·7 mètres in height, and of the same density as the air, to balance a column of $0^{m}\cdot76$ of mercury. Consequently, the velocity due to such a height will be $v = \sqrt{19\cdot62 \times 7955\cdot7} = 395$ mètres, the answer sought, or the velocity with which atmospheric air, at a temperature of 0 degrees, would re-enter an exhausted vessel.

In cases where there is no occasion to keep account of the changes in volume and density caused by temperature, this problem offers no difficulty; and it is in this sense that we shall find the means of applying it to steam, of which the Tables at page 416 give the pressure and density in relation with the temperature, which, consequently, may be omitted from the foregoing calculation.

The general formula for finding the velocity of a gas or steam is therefore the following:

$$v = \sqrt{2g(P - p)\frac{d'}{d}};$$

wherein $v$ represents the required velocity in a second of time;

| | | |
|---|---|---|
| $g$ | „ | the intensity of gravitation, equal to 9·8088; |
| P | „ | the absolute pressure of the gas or steam, in mètres of mercury; |
| $p$ | „ | the pressure of the medium where the flow takes place, epxressed in the same units. |
| $d'$ | „ | the density of mercury compared with that of water and equal to 13·598; |
| $d$ | „ | the density of the flowing gas, also compared with that of water. |

By introducing the fixed quantities into the preceding general formula, we first of all get the following expression:

$$v = \sqrt{\frac{2 \times 9\cdot8088 \times (P - p) \times 13\cdot598}{d}};$$

which may be simplified by obtaining the product of these same quantities, till it finally becomes

$$v = \sqrt{\frac{266\cdot76\,(P - p)}{d}}.$$

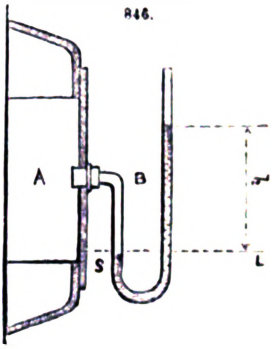
If the pressure $P - p$ were expressed in atmospheres and fractions of atmospheres, it would be necessary, in order to get the real initial height in mètres of mercury, to multiply it by the height of mercury that balances one atmosphere.

Thus modified, the formula would be

$$v = \sqrt{\frac{2 \times 9\cdot8088 \times 0\cdot76(P - p)13\cdot598}{d}}$$

by simplifying as before, we get

$$v = \sqrt{\frac{202\cdot7376\,(P - p)}{d}}.$$




The resultant pressure $P - p$, constituting the initial height of the effective velocity of the flow, may be derived from direct observation, according to the disposition of the instrument used in ascertaining it. That instrument would be the *Air Manometer*, or differential indicator of pressure, which may be used to measure the elastic force of a gas or steam in relation to a certain ambient medium.

Let us suppose a vessel A, Fig. 846, to enclose some aëriform fluid, at a higher pressure than that of the medium in which it is placed. If we attach to it a tube B containing mercury, bent in the shape of the letter U, with its shorter branch communicating with the interior of the vessel, while its longer one is left open at the top, the internal pressure, acting upon the mercury, will cause it to rise in the open branch. To find the conditions of equilibrium of the mercury, when it is thus displaced, it will be sufficient to draw a horizontal line S L through the summit of the lower column, and then examine the nature of the pressure to which the mercury is subjected at every

point of that line. In the longer branch it is equal to the pressure of the ambient medium, plus the height $h$ to which the mercury has been raised in the tube; and as it must be the same in the shorter branch, and is due entirely to the pressure in the reservoir A, we conclude that that pressure is equal to the external pressure, plus the height $h$ of the mercury. Consequently, that height is precisely equal to the difference of the two pressures, and is none other than $P - p$, which figures in the preceding calculation.

For the future, therefore, every initial pressure of the velocity of a flow will be represented in our operations by a column $h$ of mercury, observed in strict accordance with the foregoing method. It is that pressure which, estimated in mètres, must be multiplied by the ratio of the density of the mercury to that of the fluid under consideration, in order to obtain the real height which becomes the initial of the velocity with which the fluid flows.

*Problems relating to the Flow of Steam through Narrow-edged Orifices.*—Let us propose to find the velocity with which steam would flow in a medium of determinate pressure.

First example.—Find the velocity with which steam would flow through a narrow-edged orifice into the open air under a pressure of 3 atmospheres.

Solution.—Steam, under a pressure of 3 atmospheres, is represented by a column of mercury of $P = 0{\cdot}76 \times 3 = 2^{m}{\cdot}28$; and the Table at page 405 indicates that its density is $d = 0{\cdot}001615$. On the other hand, if the pressure of the ambient medium is 0·76, the required velocity will be

$$v = \sqrt{\frac{266{\cdot}76 \times (2{\cdot}28 - 0{\cdot}76)}{0{\cdot}001615}} = 502 \text{ mètres.}$$

Second example.—Find the velocity with which steam flows at a pressure of 5 atmospheres, difference of pressure between the reservoir and the medium in which the flow takes place being measured by a column of mercury = $0^{m}{\cdot}45$.

Solution.—We have $P - p = 0{\cdot}45$; and $d' = 0{\cdot}0025763$, according to the same Table; whence

$$v = \sqrt{\frac{266{\cdot}76 \times 0{\cdot}45}{0{\cdot}0025763}} = 216 \text{ mètres.}$$

Third example.—Find the velocity of steam under a pressure of 3·75 atmospheres, the pressure of the medium in which it flows being 1·80 atmosphere.

Solution.—By the same Table to which we have referred in the two preceding examples, we find that the density of steam at 3·5 and 4 atmospheres is 0·0018589 and 0·0020997 respectively; therefore, the density of steam at 3·75 must apparently be a mean between these two numbers; that is,

$$d' = \frac{0{\cdot}0018589 + 0{\cdot}0020997}{2} = 0{\cdot}0019793.$$

The pressure, expressed in atmospheres, will this time be

$$P - p = 3{\cdot}75 - 1{\cdot}80 = 1{\cdot}95.$$

Consequently, by a suitable adaptation of the foregoing formula, we have

$$v = \sqrt{\frac{202{\cdot}7376 \times 1{\cdot}95}{0{\cdot}0019793}} = 447 \text{ mètres.}$$

The above examples being sufficient to illustrate the application of the rule, we will not add any more; but merely make a few remarks called forth by the rule itself.

The arrangement of the formula shows the general mode in which gases flow, and further points out that,

1st. *The velocities are proportional to the square roots of the effective pressures;* that is to say, to the excess of pressure that causes the flow;

2nd. *They are inversely as the square roots of the densities.*

From which we conclude, in addition, that when a gas is compressed whose density is proportional to the pressure it bears, with an even temperature, the velocities are always equal, whatever may be the degree of compression.

With regard to steam having a maximum of elasticity whose density is not proportional to the expansion, there exists, however, a limit where the velocity of the flow ceases to increase with the pressure.

For instance, let us suppose two currents of steam flowing into the atmosphere, the one with an expansive force of 5 atmospheres, the other of 10, and whose densities, according to the Table, page 405, are 0·0025763 and 0·0048226 respectively, and endeavour to find their corresponding velocities. We have,

$$\text{For 5 atmospheres,} \quad v = \sqrt{\frac{202{\cdot}7376 \times (5 - 1)}{0{\cdot}0025763}} = 562 \text{ mètres;}$$

$$\text{For 10 atmospheres,} \quad v = \sqrt{\frac{202{\cdot}7376 \times (10 - 1)}{0{\cdot}0048226}} = 615 \text{ mètres.}$$

That is, a difference of only 53 mètres in velocity for a difference of expansion of 5 atmospheres.

*Tables and Graphic Tracing in Reference to the Flow of Steam.*—The solution of such problems as those we have just been examining always requires a special aptitude, and too much time for ordinary practitioners, as a rule, to turn them to their fullest account; moreover, there are interests of another order involved, and not less important, that render it imperative not to trust to the uncertain results of direct calculation: a manufacturer, on the contrary, needs reliable information, such as can alone emanate from the labours of the man of science, in the quiet seclusion of

his own study, and away from every other preoccupation. That is why tables are of such undeniable utility, by enabling the solution of a proposed question promptly and with certitude; for the figures we borrow from them form part of a series in regular progression, whose terms verify one another, so to speak, by their simple connection. Therefore we have always endeavoured, as much as possible, to make them accompany the practical rules, in order to simplify calculations and ensure correct results.

It is with this view that we produce the two following Tables of the velocity of steam under the circumstances most generally met with in practice. These two Tables, which may be readily made by means of the foregoing rules, are taken from that excellent work, 'The Locomotive Driver's Guide,' by MM. Flachat and Petiet. The first relates to the flowing of steam in the open air, under pressures varying from 5 to 1·01 atmospheres; together with its density, or weight of a cubic mètre for each pressure. The second Table gives the velocity of steam under pressures of 5, 4, and 3 atmospheres, in media whose pressures vary from 4·95 to 1·25 atmospheres, while one column is reserved for the effective pressure exerted by the steam upon every square mètre of surface. This pressure is evidently the same in the three cases where the resisting pressure is the same, since the differences also are identical. Consequently, these two Tables complete the series. Afterwards we shall give a graphic tracing, whereby the same problems may likewise be solved. In all cases the flow is supposed to take place from a narrow-edged orifice; for, were its thickness considerable, and comparable to the development of a tube, the velocity would be altered. We shall have occasion to allude to this view of the subject presently.

TABLE I.—THE VELOCITY WITH WHICH STEAM ESCAPES INTO THE ATMOSPHERE UNDER DIFFERENT PRESSURES.

| Absolute Pressure of the Steam. | Weight of a Cubic Mètre. | Velocity in a Second. | Absolute Pressure of the Steam. | Weight of a Cubic Mètre. | Velocity in a Second. | Absolute Pressure of the Steam. | Weight of a Cubic Mètre. | Velocity in a Second. |
|---|---|---|---|---|---|---|---|---|
| 5·00 | 2·568 | 562 | 1·75 | 0·984 | 394 | 1·12 | 0·674 | 194 |
| 4·75 | 2·457 | 554 | 1·60 | 0·900 | 368 | 1·10 | 0·636 | 178 |
| 4·50 | 2·334 | 549 | 1·50 | 0·854 | 343 | 1·09 | 0·630 | 170 |
| 4·25 | 2·217 | 546 | 1·45 | 0·830 | 331 | 1·08 | 0·626 | 161 |
| 4·00 | 2·096 | 537 | 1·40 | 0·800 | 318 | 1·07 | 0·622 | 151 |
| 3·75 | 1·972 | 530 | 1·35 | 0·778 | 302 | 1·06 | 0·619 | 140 |
| 3·50 | 1·855 | 520 | 1·30 | 0·750 | 285 | 1·05 | 0·610 | 129 |
| 3·25 | 1·734 | 512 | 1·25 | 0·722 | 265 | 1·04 | 0·607 | 116 |
| 3·00 | 1·611 | 502 | 1·22 | 0·705 | 252 | 1·03 | 0·601 | 101 |
| 2·75 | 1·487 | 488 | 1·20 | 0·698 | 242 | 1·02 | 0·598 | 83 |
| 2·50 | 1·363 | 472 | 1·18 | 0·681 | 232 | 1·01 | 0·595 | 58 |
| 2·25 | 1·238 | 451 | 1·16 | 0·670 | 220 | 1·00 | 0·590 | 0 |
| 2·00 | 1·111 | 427 | 1·14 | 0·658 | 213 | .. | .. | .. |

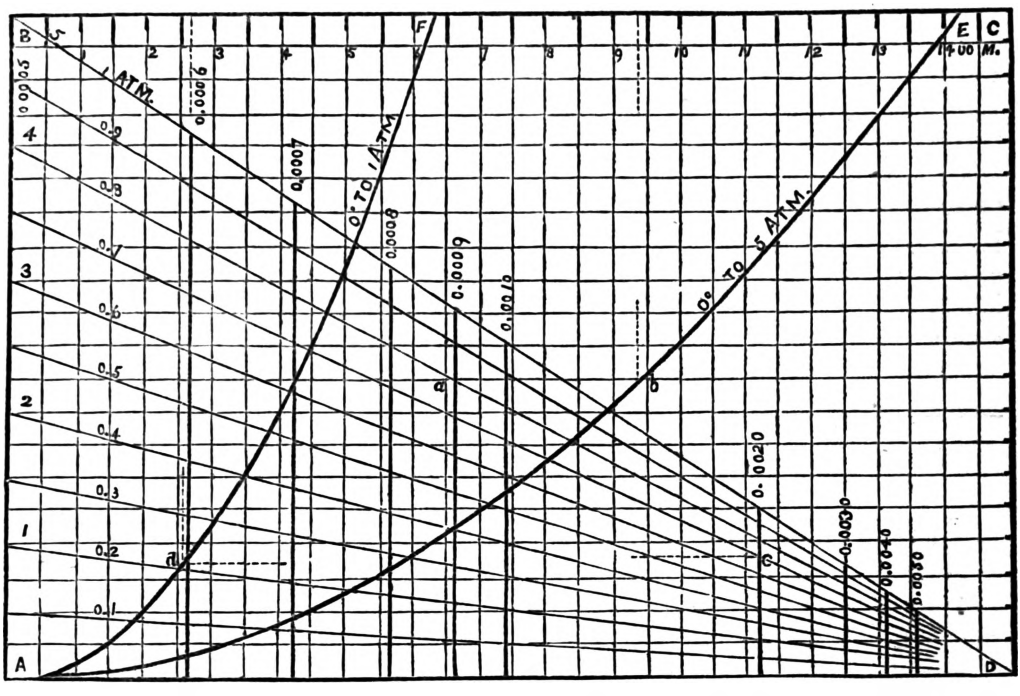
TABLE II.—THE VELOCITY WITH WHICH STEAM ESCAPES INTO MEDIA OF DIFFERENT PRESSURES.

| STEAM AT 5 ATMOSPHERES ABSOLUTE. | | | STEAM AT 4 ATMOSPHERES ABSOLUTE. | | | STEAM AT 3 ATMOSPHERES ABSOLUTE. | | |
|---|---|---|---|---|---|---|---|---|
| Pressur in the Receiver. | Effective Pressure in kilos. on every Square Mètre. | Velocity in Mètres in one Second. | Pressure in the Receiver. | Effective Pressure in kilos. on every Square Mètre. | Velocity in Mètres in one Second. | Pressure in the Receiver. | Effective Pressure in kilos. on every Square Mètre. | Velocity in Mètres in one Second. |
| 4·95 | 517 | 63 | 3·95 | 517 | 69 | 2·95 | 517 | 79 |
| 4·90 | 1·034 | 89 | 3·90 | 1·034 | 97 | 2·90 | 1·034 | 112 |
| 4·85 | 1·550 | 108 | 3·85 | 1·550 | 120 | 2·85 | 1·550 | 137 |
| 4·80 | 2·067 | 125 | 3·80 | 2·067 | 139 | 2·80 | 2·067 | 158 |
| 4·75 | 2·584 | 140 | 3·75 | 2·584 | 155 | 2·75 | 2·584 | 178 |
| 4·65 | 3·618 | 166 | 3·65 | 3·618 | 184 | 2·65 | 3·618 | 210 |
| 4·55 | 4·651 | 188 | 3·55 | 4·651 | 209 | 2·55 | 4·651 | 238 |
| 4·50 | 5·168 | 198 | 3·50 | 5·168 | 220 | 2·50 | 5·168 | 251 |
| 4·25 | 7·752 | 242 | 3·25 | 7·752 | 269 | 2·25 | 7·752 | 307 |
| 4·00 | 10·336 | 281 | 3·00 | 10·336 | 311 | 2·00 | 10·336 | 355 |
| 3·75 | 12·920 | 314 | 2·75 | 12·920 | 347 | 1·75 | 12·920 | 396 |
| 3·50 | 15·504 | 344 | 2·50 | 15·504 | 380 | 1·50 | 15·504 | 423 |
| 3·25 | 18·088 | 371 | 2·25 | 18·088 | 411 | 1·25 | 18·088 | 469 |
| 3·00 | 20·672 | 396 | 2·00 | 20·672 | 439 | .. | .. | .. |
| 2·75 | 23·256 | 421 | 1·75 | 23·256 | 466 | .. | .. | .. |
| 2·50 | 25·840 | 444 | 1·50 | 25·840 | 491 | .. | .. | .. |
| 2·25 | 28·424 | 465 | 1·25 | 28·424 | 515 | .. | .. | .. |

*Graphic Tracing.*—The method of tracing which we are now going to explain, and whereby the velocity of gases through narrow-edged orifices may be ascertained, is extensively employed by French engineers, and is analagous to the rule they apply for the purpose of estimating the expenditure of water through orifices with a load upon the centre.

This one, Fig. 847, is so arranged as to give the maximum velocity of gases having densities, compared with that of water, which vary from 0·0005 to 0·005, and relative pressures from 0 to 5 atmospheres. A series of right lines, starting from the point D, corresponds, for the curve A E,

847.




to pressures varying from 1 to 5 atmospheres, and, for the curve A F, from 0·1 to 1 atmosphere. Another series of vertical lines, including A B, represents the densities from 0·0005 to 0·005. The upper scale B C expresses the velocities in large divisions of 100 mètres.

*Use of the Tracing.*—Find the intersection of the vertical, indicating the density, with the oblique, corresponding to the relative pressure P – *p*, and, from the point of intersection, follow the horizontal line till it meets the curve; from this second point draw a vertical line which project till it reaches the scale B C, and you have the velocity required. For instance, we want the velocity of a gas whose density is 0·0009, and whose relative pressure is 4 atmospheres. We look for the intersection *a* of the vertical line 0·0009 with the oblique line 4 D, and from that intersection we follow the horizontal line till it meets the curve A E at *b*; then, by raising a vertical line from this last point to the scale B C, we then obtain an approximate reading of 940 mètres, which is the velocity sought. By strict calculation it would be 943 mètres.

To give an example of the use of the second curve, let us try to find the velocity of a gas whose density is 0·002, with a relative pressure of 0·7 atmosphere. The process is exactly the same. The intersection *c*, of the oblique 0·7 D, with the vertical corresponding to the number 0·002, gives the horizontal dotted line *c d*, which cuts the curve A F at *d*; by producing a vertical from this point on to the scale above, as before, we find about 265 mètres as the required velocity. Mathematically it would be 266 mètres.

These slight differences between the quantities found by calculation and those obtained by means of the diagram do not arise from any want of accuracy of principle in the latter, but solely from difficulties of execution, it being impossible to complete the subdivision of the scales; but by enlarging the tracing, this obstacle may be lessened or removed, and the result becomes proportionately more correct.

It would be precisely the same thing for any value not indicated in this diagram; all that is required is to suppose the line A B, as base, divided into quantities proportional to every intermediate pressure between 0 and 5 atmospheres, with oblique lines running from the several points to the point D. As regards the series of verticals of density, the same principle may be carried out, by imagining intervening lines at distances inverse to their values, for such densities as are not comprised in the diagram.

*Velocity of Gas flowing through a Pipe.*—Hitherto we have only considered the velocity of gas flowing through a narrow-edged orifice, where the friction is, consequently, insufficient to produce any noticeable effect; but when a gas passes through a pipe of a certain length, the case is very different. Then its velocity, as it leaves the pipe, is less than that which would be due to the initial pressure in the reservoir, or to its excess of pressure P – *p* over that of the medium into which it flows. There must have been, therefore, a loss of force occasioned by the resistance of the pipe to the motion of the gas. The learned D'Aubuisson found that resistance subject to the following laws:—

1st. The resistance is proportional to the length of pipe
2nd. It increases with the square of the velocity;
3rd. It is in the inverse ratio of the diameter.

Let us, consequently, call

P, the pressure within the reservoir, or its excess $h$ over that of the medium where the flow takes place, expressed in mètres of mercury;
$p$, the initial height of the effective velocity with which the gas escapes at the end of the pipe; that height likewise expressed in mètres of mercury·
$v$, the effective velocity;
L, the length of the pipe in mètres;
D, its diameter, also in mètres;
D', its diameter at the extremity, or that of the aperture whence the flow takes place, the pipe being supposed to terminate with a conical converging ajutage
$k$, an experimental coefficient.

We then have, according to D'Aubuisson, the following relations:

The mean velocity $u$ of the flow throughout the whole length of the pipe will be evidently equal to its effective velocity $v$ on leaving the ajutage, multiplied by the inverse ratio of the squares of the diameters D and D', that is to say, $u = v \times \frac{D'^2}{D^2}$; and $u^2 = v^2 \times \frac{D'^4}{D^4}$.

But the velocity $v$ is represented by $v = \sqrt{2gp}$, whence $v^2 = 2gp$, and $p = \frac{v^2}{2g}$, $p$ being, as we have said, the initial height $h$ of the velocity with which the gas escapes from the pipe. On the other hand, considering that the force absorbed by the resistance of the pipe has resulted in the reduction of the pressure from P to little $p$, that force will be expressed by $P - p$; so that, from what precedes, we get the following equation: $P - p = k \frac{L u^2}{D}$. But the foregoing relations give $p = \frac{v^2}{2g}$, and $u^2 = \frac{v^2 D'^4}{D^4}$; substituting, therefore, these values for $p$ and $u^2$, we obtain $P - \frac{v^2}{2g} = k \frac{L v^2 D'^4}{D^5}$, whence, extracting at once the value of $v$, we get

$$v = \sqrt{\frac{2g P D^5}{k 2g L D'^4 + D^5}}. \qquad [K]$$

This value, therefore, is that of the real velocity with which the gas escapes (setting aside its density for the moment), after traversing the whole length of the pipe, and issuing from a contracted orifice of the diameter D'.

If the contracted orifice of the ajutage were equal in diameter to the pipe, we should have D' = D, and the formula would be modified as follows:

$$v = \sqrt{\frac{2g P D}{k 2g L + D}} \qquad [L]$$

As to the value of the coefficient $k$, it is deduced from D'Aubuisson's experiments, who ascertained that of an experimental number $n$, whose mean was 0·0238, in which $2g$ enters as factor. Consequently, by performing the division we have $\frac{0{\cdot}0238}{19{\cdot}62} = 0{\cdot}0012$, which number becomes the value of the coefficient $k$. It is evident that this result is very liable to change according to the nature or state of the surface over which the gas has to pass. D'Aubuisson obtained it by making atmospheric air pass through tin tubes, which must have offered but little resistance compared with cast-iron pipes, whose surfaces are usually rough. It becomes then a matter of option either to adopt this value in the above equations, or else to substitute in the denominator the constant number 0·0238 for the factor $k 2g$, whereby the final values will be in no way changed.

To end this subject and give a few examples, we will now complete the formulas by applying the multiplier relative to the densities. The velocities represented by those formulas, such as we have defined them, are those that would correspond to heights of manometrical pressure; that is to say, expressed by columns of mercury. In order to obtain the velocities of gases having the corresponding pressures, it is sufficient to multiply, as before, the two terms beneath the radical by the ratio of the densities of the mercury and the gas under consideration. By again representing the density of the mercury by $d'$ and that of the gas by $d$, we have

$$v = \sqrt{\frac{2g P D^5}{k 2g L D'^4 + D^5} \frac{d'}{d}} = \sqrt{\frac{266{\cdot}76 P D^4}{(0{\cdot}0238 L D'^4 + D^5) d}} \qquad [M]$$

for the first formula [K], where the diameter of the orifice from which the gas flows is supposed to be different from that of the pipe. And for the second formula [L], where the diameters are equal,

$$v = \sqrt{\frac{266{\cdot}76 P D}{(0{\cdot}0238 L + D) d}}. \qquad [N]$$

It may be useful, however, to observe that, in the latter case, the coefficient ought perhaps to be modified, since it was obtained by means of pipes with a contracted end. But the error committed by leaving it as it is would be of very little importance, considering that in practice the departure from theoretical results is generally far greater.

*Problems relating to the Passage of a Gas through a Pipe.*—Let us endeavour successively to find with what velocity both air and st m would flow, under the two separate conditions:—1st, where the pipe is terminated by a conical *ajutage*, diminishing the diameter where the gases escape; 2nd, where the diameter is the same throughout.

First example.—Find the velocity with which air flows through a pipe having an ajutage, with the following data:—

| | |
|---|---|
| Pressure or height $h$ at the commencement of the pipe .. | $P = 0{\cdot}10$ mètres. |
| Length of pipe .. .. .. .. .. .. .. .. .. | $L = 60$ „ |
| Diameter of pipe .. .. .. .. .. .. .. .. .. | $D = 0{\cdot}20$ „ |
| Diameter of orifice where it escapes .. .. .. .. .. | $D' = 0{\cdot}05$ „ |
| Supposed density of the air (according to its temperature) | $d = 0{\cdot}0013$ „ |

Solution. Formula [M].—Admitting that the state of the pipe admits of the application of the coefficient given by D'Aubuisson, we find

$$v = \sqrt{\frac{266{\cdot}76 \times 0{\cdot}10 \times \sqrt[5]{0{\cdot}20}}{\left(0{\cdot}0238 \times 60 \times \sqrt[4]{0{\cdot}05} + \sqrt[5]{0{\cdot}20}\right) \times 0{\cdot}0013}} = 140{\cdot}9 \text{ mètres.}$$

If the velocity were not affected by friction with the pipe, it would be the same as that due directly to the pressure 0·10, according to the foregoing rules, and equal to 144 mètres. There is, then, a loss of rather more than 3 mètres, which is very little. But that is because we have supposed the orifice where the gas escapes to be much smaller in diameter than the pipe, whereby the velocity is lessened in proportion. For, the diameters being respectively 20 and 5 centimètres, the mean velocity $u$ within the pipe will only be $\frac{1}{16}$th (square of the ratio of the diameters) what it is on leaving it, barring a correction on account of the contraction of the orifice, and whose coefficient is equal to about 0·93; let

$$u = \frac{v\sqrt[2]{D'0{\cdot}93}}{D^2} = \frac{140{\cdot}9 \times 0{\cdot}0025 \times 0{\cdot}8649}{0{\cdot}04} = 7{\cdot}61 \text{ mètres.}$$

So that the loss due to friction is extremely small.

Second example.—Find the velocity of the flow under the same conditions as above, with the exception that the pipe is supposed to be completely open at the end; so that we have $D' = D$.

Solution.—By adapting the formula [N] to suit the case, we have

$$v = \sqrt{\frac{266{\cdot}76 \times 0{\cdot}10 \times 0{\cdot}20}{(0{\cdot}0238 \times 60 + 0{\cdot}20) \times 0{\cdot}0013}} = 50{\cdot}4 \text{ mètres.}$$

It will be perceived, in this instance, that the velocity is notably altered; but it must also be observed that that has been its mean velocity throughout its entire course.

Third example.—Find with what velocity steam would be discharged through a pipe into the ambient air, with a pressure of 4 atmospheres, under the following conditions:

| | |
|---|---|
| Effective pressure of the steam (3 atmospheres), or .. | $P = 2{\cdot}28$ mètres. |
| Density .. .. .. .. .. .. .. .. .. .. .. | $d = 0{\cdot}0021$ „ |
| Length of pipe .. .. .. .. .. .. .. .. .. | $L = 25$ „ |
| Uniform diameter of pipe .. .. .. .. .. .. | $D = 0{\cdot}12$ „ |

Solution. Formula [N].—The mean velocity within the pipe, as well as that with which the steam escapes, are apparently equal to

$$v = \sqrt{\frac{266{\cdot}76 \times 2{\cdot}28 \times 0{\cdot}12}{(0{\cdot}0238 \times 25 + 0{\cdot}12) \times 0{\cdot}0021}} = 220{\cdot}6 \text{ mètres.}$$

Had the velocity not been altered, we should have had

$$v = \sqrt{\frac{266{\cdot}76 \times 2{\cdot}28}{0{\cdot}0021}} = 538 \text{ mètres.}$$

The change in the velocity is, therefore, very considerable; but, as the velocity is also great, the result is simply in conformity with the theory according to which the force absorbed by friction increases as the square of the velocity.

Fourth example.—Let us take the same data as before, but with a diameter of pipe of 20 centimètres instead of 12, so as to see what effect it will have.

Solution.—Using the same formula, we have

$$v = \sqrt{\frac{266{\cdot}76 \times 2{\cdot}28 \times 0{\cdot}20}{(0{\cdot}0238 \times 25 + 0{\cdot}20) \times 0{\cdot}0021}} = 268 \text{ mètres,}$$

in lieu of $220^{m}{\cdot}6$ with a pipe $0^{m}{\cdot}12$ in diameter, and about half the maximum velocity 538 due to the relative pressure of the steam if no friction existed.

*Volumes of Steam that are discharged through simple Orifices and Pipes.*—It is clear that the only difficulty in the way of solving the question of the expenditure of gases and steam, was the ascertaining its velocity. As to the volumes discharged, they are, as in the case of incompressible fluids, the product of that velocity by the section of the orifice, and by a coefficient of contraction determined by experiment. Consequently, the latter part of the problem may be considered simply as a remark, having reference principally to the coefficient of contraction that ought to be adopted.

*Coefficients of Contraction.*—D'Aubuisson found that, as in the case of incompressible fluids, the coefficients of contraction $m$ applicable to the expenditure of gases had the following values:

| | |
|---|---|
| For a narrow-edged orifice .. .. .. .. | 0·65 |
| For a short cylindrical ajutage .. .. .. | 0·93 |
| For a short ajutage, but slightly tapering .. | 0·95 |

To obtain the real expenditure it suffices, therefore, to multiply the theoretical product by one of the above values, according to the nature of the case.

First example.—A certain gas flows through a narrow-edged orifice 5 centimètres in diameter, with a velocity equal to 150 mètres a second; find the total volume Q discharged in a minute.

Solution.—We find $Q = \frac{0{\cdot}05^2 \times \pi \times 150 \times 60 \times 0{\cdot}65}{4} = 11{\cdot}486$ cubic mètres.

Second example.—The orifice of the supply-pipe being rectangular and measuring 20 centimètres by 3, and open in full during a reduced time of 0·5 of a second, what volume of steam would enter the cylinder of an engine, supposing the pressure and density to correspond to a velocity equal to 300 mètres?

Solution.—We have $0{\cdot}03 \times 0{\cdot}20 = 0^{sm}{\cdot}006$ for the surface of the orifice. If we take 0·9 as the coefficient, then $Q = 0{\cdot}006 \times 300^m \times 0{\cdot}5 \times 0{\cdot}9 = 0{\cdot}810$ cubic mètres.

As regards the expenditure through a pipe, we may observe that, in the case of a narrow ajutage, the coefficient 0·93 may be used; but it is to be dispensed with when the pipe is cylindrical. The operation is reduced, therefore, to precisely the same terms as before.

*Note relating to the finding the Diameter of a Pipe where the Flow is to take place under certain Fixed Conditions.*—Generally speaking it is not a difficult problem to ascertain what ought to be the dimensions of an orifice in order to satisfy certain definite conditions; but it is not the same as regards the dimensions of a pipe, whose diameter, we have seen, enters as two different powers in the expression of the velocity and the expenditure. It is possible, however, to arrive at a practical result of sufficient accuracy by the aid of a simple method of which we will endeavour to lay down the elements. Of course we suppose the pipe to be uniform in diameter and without contraction. If we bring together the expression of the velocity and that which corresponds to the section of the pipe—which we have supposed all along to be circular—and multiply the one by the other, the result will evidently be equal to the volume Q discharged under the said conditions, since it will be the product of the velocity by the section. Thus we have formula [N]

$$\sqrt{\frac{266{\cdot}76\,P\,D}{(0{\cdot}0238\,L + D)\,d}} \times \frac{3{\cdot}1416\,D^2}{4} = Q.$$

Squaring the two members, and representing by $a$ the product of the invariable quantities, with the exception of the coefficient 0·0238, it becomes $Q^2 = \frac{a\,P\,D^5}{(0{\cdot}0238\,L + D)\,d}$.

As we want, now, to find the diameter D, we must draw its value from this formula. But as that operation would be very difficult to perform in a direct manner, on account of the two powers D and $D^5$, we extract the value of $D^5$ as if D were known, and we find

$$D = \sqrt[5]{\frac{(0{\cdot}0238\,L + D)\,Q^2 d}{a\,P}}.$$

And as $a$ is a fixed number, and equal, as may be seen, to

$$\left(\frac{3{\cdot}1416}{4}\right)^2 \times 266{\cdot}76 = 164{\cdot}5576,$$

we extract its fifth root, which is equal to 2·8, whereby we divide the unity, which gives 0·3571; call it 0·36, and taking that number as multiplier from the radical, we arrive at this last expression:

$$D = 0{\cdot}36 \sqrt[5]{\frac{(0{\cdot}0238\,L + D)\,Q^2 d}{P}}. \qquad [O]$$

Now, in order to work by means of this formula and finally disengage D, this is what may be done: We operate, in the first place, by considering D under the radical equal to 0; we shall thus obtain a first value of D, though rather a weak one. We then recommence the process, this time assigning to D under the radical the approximate value found by the first operation. The second value of D thus obtained, will always be near enough for all practical purposes; if, however, these two successive values were to present a very wide difference, the accuracy of the second value might be tested by performing a third operation wherein that value would in turn be substituted for D under the radical, and might be considered correct if the result of the said operation turned out to be apparently equal to it.

Example.—Be it required to find the diameter D of a pipe under the following conditions:

| | |
|---|---|
| Length of pipe .. .. .. .. .. .. .. | L = 100 mètres |
| Expenditure of gas in a second of time .. | Q = 0·5 cubic mètre |
| Relative pressure of the gas .. .. .. .. | P = 0·7 mètre (mercury) |
| Density of the gas .. .. .. .. .. .. | $d$ = 0·002 |

Solution. Formula [O].—By considering D under the radical equal to 0, we have

$$D = 0{\cdot}36 \sqrt[5]{\frac{(0{\cdot}0238 \times 100^m + 0) \times 0{\cdot}25 \times 0{\cdot}002}{0{\cdot}7}} = 0^m{\cdot}101,$$

a first value of D, which we substitute in its place under the radical, in order to perform the second operation, when we find

$$D = 0{\cdot}36 \sqrt[5]{\frac{(0{\cdot}0238 \times 100^m + 0{\cdot}101) \times 0{\cdot}25 \times 0{\cdot}002}{0{\cdot}7}} = 0^m{\cdot}101;$$

and as this last result is the same as the first, we may be sure that we have the true value of the required diameter, and no further operation is necessary. As it may appear strange that the same

answer should be obtained from two formulas, one of which contains a quantity more than the other, we must observe that the results are, in reality, different, but that that difference manifests itself only in a series of decimals that are not appreciable in practice. In general, the very disposition of the formula leads us to understand that it is sufficient if the length of the pipe is equal to several times its diameter—which is almost always the case and may be ascertained beforehand—for the result found by the first operation to give the true practical dimension required. A single operation would, therefore, be sufficient; but it is as well to verify it, either by repeating it and giving D its value beneath the radical, or by finding the expenditure of the pipe according to the conditions laid down.

Thus, in order to test the preceding operation, if we seek the velocity of the flow according to the length of pipe, 100 mètres, its diameter 0·101, and the pressure 0·7, we find it to be 62·60 mètres, which, multiplied by 0·008012, area of the circle 9·101, gives 0·501 cubic mètre as the expenditure of the pipe. It is needless to add that this result may be considered to be in strict conformity with the primitive data of the problem.

We shall limit ourselves to this much, considering that we have said all that is useful touching the expenditure of steam and gases; observing, however, that the preceding rules apply where the pipes are straight or curved, but not where they have contractions or sharp angles, such as to destroy a portion of the *vis viva* of the fluid in motion. At the conclusion of this article we shall, as usual, give a list of such authors as may be consulted by those of our readers who are desirous of obtaining more complete notions upon the subject.

Physical Properties of Steam.—The functions of steam motors repose upon the mechanical properties of the aëriform fluid produced by water in its physical change called *the state of steam.* Before studying, therefore, the construction of such machines, it is indispensably necessary that we should give an exact account of the circumstances whereby the phenomenon of the conversion of water into steam is attended, showing the conditions under which it is accomplished; the physical effects that immediately result therefrom; the means of ascertaining their intensity; and, finally, the part taken by the chief imponderable agent, *heat* or *caloric*, and the combustible substances by which this latter is developed. Thus, it is with steam-engines as with hydraulic motors, the motive power is borrowed from natural agents, namely, Caloric and Gravity.

By the means of caloric, an inert liquid, possessing gravity only, is transformed into an expansive gas deriving its power from itself. When that said liquid has been previously elevated by natural forces, gravity seems to use it as a sort of receiver to whom it has entrusted its power in order that it may be restored at a moment when that same liquid may be utilized as a *fall.*

The comparison of these two imponderable agents, brought into play for the purpose of obtaining motive force, is suggestive of a very interesting remark, which is, that, in both cases, one of the two agents, caloric, has been the primal cause of the mechanical effect obtained, since the water, elevated so as to produce a useful fall, was raised solely by the action of heat, which caused it to evaporate so that it might afterwards fall in the shape of rain, forming streams and rivers. It is quite certain that without that cause water would only be known to the world as a uniform level, precisely on account of that gravity which forbids its being raised otherwise than by the development of some mechanical power of corresponding intensity.

It may, therefore, be said that, in the two systems of motors, *water* and *steam*, the first physical expenditure is supplied by caloric.

In hydraulic motors, it effects the change of state by opposing the action of gravity, which will restore later that expenditure of action after the return from the vaporized to the liquid state.

In steam motors, the effect of caloric is immediate, while that of gravity is, for the time, eliminated.

But, even in this latter case, it will be easy to see that the laws of gravity still intervene to measure, in a manner, the effects produced by caloric, which may always be expressed—like every other mechanical work—by the raising of weights.

It becomes, therefore, very easy to understand this transformation of natural powers, so intimately connected that their effects are equal, and exactly compensate one another. This will, perhaps, serve to explain the error into which some persons have fallen, who fancied that it could create an advantageous motor, by raising water with the aid of an artificial vacuum formed by the condensation of steam, and then utilizing it by allowing it to fall upon a wheel or other contrivance.

But it must be evident that a volume of water, raised at the expense of a certain quantity of steam, cannot develop by its fall a greater power than that which would have been produced by the direct use of the steam: it is better, therefore, to adopt this last method.

*Definition of Steam.*—In nature, bodies present themselves under three different forms,—the solid, the liquid, and the gaseous or aëriform.

Were it not for the particular circumstances under which these bodies are generally maintained, some in one state, some in another, so as to enable us to classify them as above,—with much stronger reason might we say that bodies have no absolute state, but may present themselves indifferently under the one or under the other, which is true.

The normal condition of the medium in which we exist is the sole cause of the distinction that has been admitted into common parlance. We say that water is a liquid; that metals are solids; that air is a gas, and so on; and yet water may become solid as well as gaseous, and metals may be made liquid and even into gas. If air appears not to possess the property of liquefying or solidifying, it is in all probability because we are ignorant of the means requisite—not because they do not exist: other gases are known to be capable of these changes.

So that,—setting aside air for the present,—the physical state of a body is a mere question of temperature. It is certain that, if that of the earth nowhere exceeded one degree centigrade below zero, water would be classed as a solid; and, in the opposite event if the temperature rose to a sufficient degree of heat, water would be called a gas.

Having explained this in a general manner, we will now occupy ourselves exclusively with that which concerns the changes to which water may be subjected. But, however great our desire may be to simplify as much as possible the study of steam, it will not avail our readers unless they have some knowledge in physics, upon which we cannot enter here. We will therefore suppose that knowledge to exist, embracing the theory of gravity, hydrostatics, the equilibrium of gases, and the phenomena of heat. When occasion requires, moreover, we shall not fail to recall to mind the fundamental laws of those different branches of physics.

*Principles of the Formation of Steam.*—If a certain quantity of water be placed in a vessel or poured upon the ground in the open air, it will gradually diminish in volume, and, in course of time, disappear altogether unless renewed. The water is then said to have *evaporated*, or transformed itself into steam—that is to say, a gas—invisible like air and mingling with it.

If, in lieu of leaving the water contained in the vessel simply exposed to the temperature of the surrounding atmosphere, we place it over a fire, it begins to heat, then to *boil*, and finally disappears, leaving the vase that contained it completely dry, provided no liquid be added, and that the fire be kept up a sufficient length of time. This time the water is said to have been *vaporized*, which means that it has again been converted into steam, but rapidly, and accompanied by the phenomenon of ebullition.

We see, then, that the transformation of water into steam, or its change from the liquid to the gaseous state, takes place under two different conditions, which are,

1st. *Slow evaporation* in the open air, and without any effervescence;

2nd. *Vaporization*, which signifies the rapid and tumultuous conversion into steam.

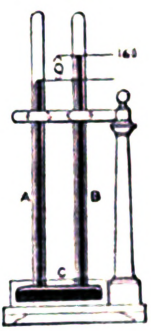
These two methods, though differing in appearance, in no way affect the properties of steam. We shall learn, as we proceed, that those conditions only prove that steam is formed at all temperatures; and that, in both cases, when passing from the liquid to the gaseous state, the water acts merely in obedience to a repulsive force of its molecules, which have a constant tendency to separate from one another, overcoming the resistance of the ambient medium. The formation of steam in vacuum fully illustrates this truth, and might, judging from the mere superficial evidence of our senses, constitute a third method, whereas it is but an explanation of one single general phenomenon. We shall also see that this expansive force of the liquid molecules increases with the temperature of the water.

*Formation of Steam in Vacuum.*—It has been shown by means of the most conclusive experiments that the formation of steam is a permanent property in liquids, and that they would immediately assume that state were they not prevented, under the ordinary conditions of their temperature, by the external pressure of the medium in which they are placed.

Effectually, if water be introduced into a space entirely void of air and where no pressure exists, that is to say, in vacuum, it vaporizes instantaneously; so that of an apparent and fluid body, there only remains an invisible gas like air; and this phenomenon is accomplished no matter what the temperature of the liquid may be. This curious fact is demonstrated by physicists in a very remarkable experiment, and the most satisfactory, perhaps, that could have been devised.

Two mercurial barometers being disposed in the manner indicated by Fig. 848, and both at first marking the atmospheric pressure, like B, a drop of water, whence the air has been carefully expelled by distillation, is introduced into one of the barometrical tubes, say A, at its lower end by the aid of a bent pipe. On account of its specific lightness the drop of water soon reaches the summit of the mercurial column and enters the barometrical chamber or Torricelli's vacuum.

848.




But here, and at the same time, an extraordinary phenomenon takes place: the column of mercury falls while the drop of water disappears, entirely or in part, according to certain conditions which we shall point out presently. Be that, however, as it may, the fall in the mercury is sufficiently great not to be attributed to the mere weight of the liquid, which, by virtue of the immense difference existing between its own density and that of the metal, would, at the most, have caused a depression in the latter scarcely appreciable. Neither can it be accounted for by a certain quantity of atmospheric air disengaged from the water, since this last was previously purged by distillation.

We are, therefore, bound to conclude from this experiment that a gaseous body has been formed in the barometrical chamber, endowed with an expansive force capable of causing the depression $a$, which may be easily measured by means of the barometer B, that has remained intact. That gas is none other than the steam arising from the water, whose molecules, no longer under the influence of atmospheric pressure, have separated from one another with an effort of repulsion which is exactly measured by the barometrical depression $a$ resulting therefrom.

So that, in principle, the transition of water to the state of gas or steam is the consequence of a natural expansion of its molecules, which only becomes manifest when it is capable of surmounting the pressure of the ambient medium.

*The Influence of Temperature on the Formation of Steam.*—The formation of steam in vacuum being a generally established fact, if, now, account be kept of the temperature at which the water was introduced into the barometer, we shall acquire the certitude that the tendency to vaporization varies with that temperature, and that, as the latter increases, so much greater is the depression of the mercurial column. In other terms, the elastic force of steam augments with the temperature of the water by which it was engendered.

The better to impress the mind with this important proposition, let us suppose, in the last experiment, that one decigramme of water was introduced into the barometer at a temperature of + 20 degrees centigrade; we recognize from observation that the depression of the mercurial column would in that case be about 17 millimètres, that is, assuming that the water lost none of

its heat in passing through the mercury; it may, therefore, be said that the pressure exerted by the steam thus formed is equivalent to a small column of mercury of that height; that is, $\frac{1}{760}$ of the entire column, or rather more than $\frac{1}{10}$ of the total atmospheric pressure.

Before enlarging more fully upon these principal properties of steam, it will perhaps be useful if we give a better explanation of what is to be understood by *steam*, and of its real constitution as compared with the notions one might be led to form thereof from a mere casual view of the question. Steam, with its property of expansion, and in that phase of formation in which we have supposed it to be, is in reality a transparent, invisible fluid, like air. The grey or white vapours that escape from a vessel containing boiling water, from the chimney of a locomotive engine, and so forth, are frequently designated as *steam;* but improperly so, since those mists are but an immense agglomeration of microscopic globules composed of a layer of liquid water enclosing steam, and floating in the air, but the whole assemblage of which does not possess the slightest elastic force. They may be regarded as the transitory form assumed by steam in returning to the liquid state caused by relative slow cooling. The phenomenon of fogs is often witnessed in the atmosphere, when the gaseous vapour which it always contains in a greater or less degree is, from some cause or other, partially condensed.

*The Maximum Elastic Force of Steam.*—It is clear, from the foregoing experiment with the barometer, that, since water only vaporizes so long as it meets with no opposition from the external pressure to which it is subjected, that vaporization ought to cease as soon as the steam already formed has acquired precisely that tension which limits, with a given temperature, the expansion of the liquid molecules. And this, in fact, is what happens. For, if a sufficient quantity of water be introduced into the barometer, the whole of it does not become transformed into steam, but a portion still remains on the top of the column of mercury after the depression of the latter has taken place. In order to attain this result it is necessary that the volume of water introduced should bear a certain relation to the size of the barometrical chamber, including the fall of the mercury. When these conditions have been fulfilled, the chamber is said to be *saturated, that the steam has attained its maximum of expansion or elastic force.* This is tantamount to saying that a sufficient pressure has been engendered to balance the tendency of the water, with its actual temperature, to transform itself through the expansive force of its molecules.

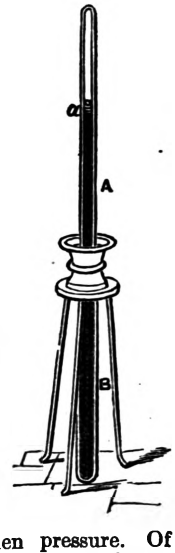
Things being in this state, if by some means we are able to enlarge the space occupied by the steam, fresh quantities of water will be vaporized, and if we continue increasing it, not only will the whole of the water disappear, but the steam will still fill it and yet its pressure will not be completely destroyed.

If we have recourse to the opposite process, and lessen the space, a portion of the water that had been converted into steam returns at once to the liquid state; and should we persevere in reducing it until it equals exactly the volume of the water originally introduced, the entire mass then assumes its primitive form.

These properties, which are an inevitable consequence of what we have said touching the equilibrium between the tension of the steam formed and the natural expansion of the molecules of the liquid mass, are rendered clearly evident by the aid of an instrument called a *well barometer.*

This instrument consists of an ordinary barometer, A, Fig. 849, but whose basin is formed of a deep tube B, widening into a cup at the top and partly filled with mercury, constituting a sort of *well* into which the tube A may be plunged to a considerable length. As the height of the mercurial column is invariable and has for its base the level of the open surface in the basin, it follows, as a matter of course, that, by immersing the tube A in the well, the deeper it goes the smaller in proportion will the barometrical chamber become. If, consequently, we make a drop of water *a* pass to the surface of the mercurial column, as before, the space occupied by the steam will increase or diminish according as we raise or lower the tube in the well. By raising it the drop of water grows gradually smaller, and finally disappears altogether. By continuing thus to augment the barometrical chamber, the mercury—repulsed at first by the elastic force of the steam—will be seen to reascend towards its normal height, but without ever exactly attaining it, even could the tube be indefinitely raised; which clearly proves that the steam continues to occupy the additional spaces offered to it, and always exerts a pressure whose intensity is in the inverse ratio of those spaces.

849.




If now we replunge the tube A deep into the well, we shall see, little by little, the water reappear, and the whole of the steam will return to the liquid state if we immerse the tube sufficiently deep to reduce the vacuum to the dimensions of the drop of water.

This experimental result has caused physicists to say that, although steam, like gases, possesses an indefinite force of expansion which enables it to dilate as the dimensions of the vase containing it are increased; it is not, like most gases, indefinitely compressible; but, that it has a *maximum of elasticity or compression* beyond which it ceases to resist, and, by condensing, returns to the liquid state. But this, however, in no way proves that it has not properties entirely identical with those of gases; for, beyond this fact, which nothing authorizes us to affirm, that gases are susceptible of any amount of compression, it has been observed that several of them liquefy in reality, if subjected to sufficien pressure. Of this number is carbonic acid, for instance, which becomes liquid under a pressure of 45 atmospheres. Other gases liquefy with a much less pressure. But steam offers an advantage seldom or never met with in permanent gases, and that is, the facility of observing the condensation that takes place if we endeavour to compress it beyond a certain limit. It is that limit that has been termed the *maximum of elastic force*, and which varies with the temperature of the liquid by which the steam was generated. It would appear, then, from this, that in vacuum, when the quantity

of liquid is sufficient, the steam acquires immediately its maximum of elastic force, after which the vaporization instantly ceases if no modification of space takes place. By saying that at that moment the space is *saturated*, we use an expression that renders well the idea we wish to convey of the formation of steam which can only continue to disengage itself so long as its own pressure offers no opposition to the continued expansion of the liquid molecules.

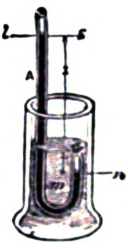
*The Relation between the Elastic Force of Steam and its Temperature.*—Now that the principle of the formation of steam has been rendered intelligible through the evidence afforded by its development in vacuum, it becomes easy to show how its power increases with its temperature. In the foregoing experiment—the instrument used being the barometer, which does not admit of the measurement of a greater pressure than that of the atmosphere balanced by its column of mercury—we were unable to observe the effects of steam at a higher temperature than 100 degrees, in which case the pressure would be sufficient to entirely overcome the said column. The experiments, therefore, could only range between the temperatures of zero—the lowest limit at which water liquefies—and 100 degrees, when, the mercury in the vertical tube being on a level with that in the basin, the instrument ceases to act. This first result has proved, however, of very great importance, since it has afforded an exact knowledge of the general properties of steam, and has enabled us, moreover, to establish a unity of measure of its power. Without rejecting the facility of measurement presented by the barometer, the grand unity, that has been chosen as standard, is the pressure of the atmosphere, to which that of steam becomes equal at a certain temperature, as seen already. Consequently, when the pressure of steam is capable of replacing the column of mercury in balancing the external air, it is said to be equal to *one atmosphere*. That pressure, as expressed by weight and unity of surface, is, we know, equal to 1·0333 kilogramme on every square centimètre. It is simply the weight of a column of mercury measuring 76 centimètres in height and 1 centimètre square at the base.

If, as we have explained elsewhere, water, when heated in the open air, cannot exceed the temperature of 100 degrees centigrade, the case assumes a very different aspect when it is confined in a close vessel from which the steam is unable to escape into the atmosphere as fast as it is formed. The temperature of the water may then be heightened, giving forth steam whose pressure increases, we might almost say, indefinitely.

In order to furnish a first demonstration of this fact, physicists have recourse to a very simple experiment, of which we must say a few words.

A tube, A, Fig. 850, bent in the form of an U, but having its branches of unequal length—the longer being open to the air, while the shorter is hermetically closed—is partially filled with mercury, and a drop of water is made to pass to the summit of the column in the sealed end, as seen at *a*.

850.



Having made these arrangements, if we now plunge the instrument into an oil bath at a temperature greater than 100 degrees, steam begins to form, spreading from *a* to *m n*, and thrusting back the mercury which rises in the longer branch of the tube to a certain height *s l*. It then becomes evident that the steam exerts a pressure superior to that of the atmosphere, since when in its liquid state it bore that pressure transmitted through the mercury, but repulsed it as soon as it became transformed.

Its real pressure is therefore equal to that of the atmosphere plus the column of mercury H, measured from the open surface *s l* to the horizontal line *m n*, passing through the summit of the column in the short branch of the tube.

Be it granted, for example, that, in the above experiment, the larger column of mercury has reached a height H equal to 45 centimètres; how should we express ourselves in order to indicate the pressure of the steam that has been formed, allowance for the expansion of the mercury not being taken into consideration?

With a barometer indicating that, at the moment of the experiment, the atmospheric pressure is balanced by a column of mercury 76 centimètres in height, the steam will have overcome a resisting column of 76 + 45 = 121 centimètres. In order to establish the relation between the height of that pressure and that of the atmosphere, we say, $\frac{121}{76} = 1{\cdot}592$; meaning that the pressure of the steam is equal to 1 atmosphere plus 592 thousandths.

As regards the expression of the pressure by weight and unity of surface, adopting the centimètre square for the latter, it is sufficient to know the density of the liquid raised, and to ascertain its weight according to its volume. The density of mercury being 13·598, or 13·598 grammes for a cubic centimètre, we should have 13·598 × 121 = 1645 grammes. We then say that the steam exerts a pressure represented by a weight equal to 1·645 kilogramme upon every centimètre square.

Let us remark, in order that no doubt may present itself to the mind respecting the condition of vacuum laid down just now for the formation of steam,—but which does not apply in the above experiment,—that it must be remembered that a vacuum does not otherwise modify the phenomenon of the generation of steam, beyond allowing its instantaneous accomplishment, and at the lowest temperatures, even that of freezing. Consequently, the properties observed are the same in both instances. Were it possible for us to transport ourselves to some place where the barometrical pressure could reach a height of 121 centimètres, the experiment might be performed with that instrument, and the results obtained would be precisely identical.

Although the last experiment has enabled us to note the pressure of steam for temperatures a little above 100 degrees, it would not be so were it to become very much greater: for, as steam rapidly acquires very considerable pressure, it is more than probable that the instrument would not be able to resist it.

The first men, after English accurate investigators, to thoroughly investigate this question in France were the celebrated Arago and Dulong, to whom the Academy of Sciences entrusted the

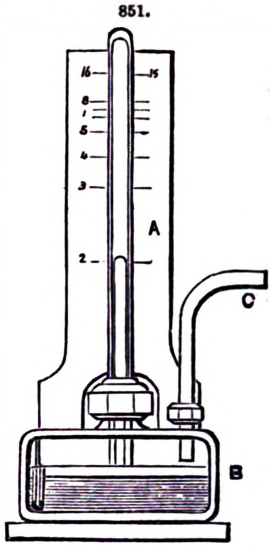
important and useful mission of ascertaining the elastic force of steam throughout the most extended scale of temperatures possible. That laborious work was only terminated in 1830.

This is how these illustrious savants operated so as to obtain high degrees of temperature, and be able, at the same time, to measure the corresponding elasticity of the steam.

The water was enclosed in a boiler made of strong sheet iron, perfectly air-tight, and fixed in a brick furnace. Two gun-barrels, open at the top and closed at the bottom, were then inserted into the lid, descending, the one to the lower part of the vessel, the other to the upper, where the steam was confined. Both were filled with mercury, which acquired necessarily the same temperature as the fluid into which the barrels were plunged, and which could be easily measured by the aid of thermometers so disposed as to suffer no loss by cooling. Being thus in a position to know at any moment the temperature of the liquid and of the steam arising from it, a communication was established between the latter and an instrument suitable for measuring its corresponding tension.

That instrument is what has been called later a *Condensed-air Manometer*, and is composed, in principle, of a stout glass tube A, Fig. 851, closed at its upper extremity, while its lower one, which is open, dips into a basin B, containing mercury. This tube is carefully adjusted to the basin, so as to cut off all communication with the external atmosphere. A second tube C, similarly fitted, has one of its ends inserted likewise into the basin, but without dipping in the mercury; while the other is connected with the vessel in which is the fluid whose elastic force has to be ascertained.

851.




In order to understand the working of the manometer, let us suppose, before beginning the experiment, that perfect communication exists between the several parts, and that the whole is filled with atmospheric air; it is then clear that the level of the mercury within the glass tube will be the same as that in the basin, the pressure being equal throughout. Soon, however, the temperature of the liquid beginning to rise, steam is formed in the boiler, and the air it contained is thereby gradually expelled through an outlet temporarily reserved for that object. So long as the temperature has not reached that point at which the tension of the steam exceeds that of the atmosphere, the level of the mercury remains unaltered; but, from the instant that occurs, from the special arrangement of the apparatus, the temperature of both the liquid and the steam augments, as well as the elastic force of the latter: the mercury is then seen to rise in the tube on account of that excess of tension, which is felt alike in the basin containing the mercury and in the vessel where the steam is generated. But, as the mercury rises, it necessarily compresses the air confined in the upper portion of the tube, and whence it is unable to escape: the elastic force of that compression must be the same as that of the steam, by virtue of the equal transmission of pressure, barring a correction on account of the weight of the column of mercury raised. This compression of the air above the mercurial column is, therefore, the measure of the elastic force of the steam; and is the more easily determinable that air is compressed in accordance with a well-known law, discovered by Boyle, and defined in the following terms:—

*The volumes of gases are inversely proportional to their pressures.*

We shall revert again to that law, to which we merely allude for the better intelligence of the present experiment.

Consequently, if we adopt as unity the volume of air contained in the tube at the commencement of the operation, with the ordinary atmospheric pressures, when, by the rising of the mercury, that volume has been reduced one-half, we shall conclude that it supports a double pressure, or 2 atmospheres; when it has been reduced to one-third, that the pressure is triple, or equal to 3 atmospheres; when to one-quarter, 4 atmospheres, and so on.

This disposition of the manometer enables us, therefore, at any moment to ascertain the elastic force of the steam formed, while the thermometers give its temperature. We may add that the experiments have been carried as far as 24 atmospheres. From these experiments and others, a very complete Table has been made of the corresponding elastic force of steam for various temperatures and also a formula whereby the intermediate quantities may be calculated. We subjoin that portion of the Table which is most likely to prove useful in practice. The elastic forces given are maxima, that is to say, those, at each temperature, where the steam *saturates the space* and would commence returning to its liquid state if an attempt were made to compress it. The Table is divided into two parts, the first comprising the elastic forces of steam for temperatures ranging from 0 to 100 degrees, the second the temperatures corresponding to elastic forces that vary from 1 to 50 atmospheres.

A third Table has been added to these, based upon calculation, for pressures ranging between 100 and 1000 atmospheres. Although it is the opinion, even of savants, that the numbers it contains are not to be relied upon, since they have not the sanction of experiment, still we give it, that it may serve for comparison.

The two first Tables, on the contrary, afford all the guarantee demanded in practice; and from more recent researches, made by M. Regnault, it turns out that, with the exception of a few slight differences, their correctness may generally be depended upon.

In examining these Tables with a little attention we are struck with a very remarkable result,—it is the rapidity with which the tension of steam increases, compared with its temperature, and how very far the two effects are from being proportional. This fact may be rendered still more apparent by means of a graphic tracing, which, being constructed with the assistance of the numbers given in the Tables, brings it more prominently before the understanding.

TABLE I.—THE MAXIMUM ELASTIC FORCE OF STEAM FOR TEMPERATURES FROM 0 TO 100 DEGREES CENTIGRADE.

| Degrees, centi-grade. | Tension of Steam in millimètres. | Pressure in kilos. on 1 centimètre square. | Degrees, centi-grade. | Tension of Steam in millimètres. | Pressure in kilos. on 1 centimètre square. | Degrees, centi-grade. | Tension of Steam in millimètres. | Pressure in kilos. on 1 centimètre square. |
|---|---|---|---|---|---|---|---|---|
| 0 | 5·059 | 0·0069 | 34 | 38·254 | 0·0520 | 68 | 209·440 | 0·28454 |
| 1 | 5·398 | 0·0074 | 35 | 40·404 | 0·0549 | 69 | 219·060 | 0·29761 |
| 2 | 5·748 | 0·0078 | 36 | 42·743 | 0·0581 | 70 | 229·070 | 0·31121 |
| 3 | 6·123 | 0·0084 | 37 | 45·038 | 0·0612 | 71 | 239·450 | 0·32532 |
| 4 | 6·523 | 0·0089 | 38 | 47·759 | 0·0646 | 72 | 250·230 | 0·33996 |
| 5 | 6·947 | 0·0094 | 39 | 50·147 | 0·0681 | 73 | 261·430 | 0·35518 |
| 6 | 7·396 | 0·0101 | 40 | 52·998 | 0·0720 | 74 | 273·030 | 0·37094 |
| 7 | 7·871 | 0·0107 | 41 | 55·772 | 0·0758 | 75 | 285·070 | 0·39632 |
| 8 | 8·375 | 0·0114 | 42 | 58·792 | 0·0799 | 76 | 297·570 | 0·40428 |
| 9 | 8·909 | 0·0122 | 43 | 61·958 | 0·0818 | 77 | 310·490 | 0·42184 |
| 10 | 9·475 | 0·0129 | 44 | 65·627 | 0·0892 | 78 | 323·890 | 0·44004 |
| 11 | 10·074 | 0·0137 | 45 | 68·751 | 0·0934 | 79 | 337·760 | 0·45888 |
| 12 | 10·707 | 0·0146 | 46 | 72·393 | 0·0983 | 80 | 352·080 | 0·47834 |
| 13 | 11·378 | 0·0155 | 47 | 76·205 | 0·1035 | 81 | 367·000 | 0·49860 |
| 14 | 12·087 | 0·0165 | 48 | 80·195 | 0·1090 | 82 | 382·380 | 0·51950 |
| 15 | 12·837 | 0·0170 | 49 | 84·370 | 0·1166 | 83 | 398·280 | 0·54110 |
| 16 | 13·630 | 0·0186 | 50 | 88·743 | 0·1206 | 84 | 414·730 | 0·56345 |
| 17 | 14·468 | 0·0197 | 51 | 93·301 | 0·12676 | 85 | 431·710 | 0·58652 |
| 18 | 15·353 | 0·0209 | 52 | 98·075 | 0·13325 | 86 | 449·260 | 0·61086 |
| 19 | 16·288 | 0·0222 | 53 | 103·060 | 0·13999 | 87 | 467·380 | 0·63498 |
| 20 | 17·314 | 0·0235 | 54 | 108·070 | 0·14710 | 88 | 486·090 | 0·66040 |
| 21 | 18·317 | 0·0250 | 55 | 113·710 | 0·15449 | 89 | 505·380 | 0·68661 |
| 22 | 19·447 | 0·0265 | 56 | 119·390 | 0·16220 | 90 | 525·28 | 0·71364 |
| 23 | 20·577 | 0·0281 | 57 | 125·310 | 0·17035 | 91 | 547·80 | 0·64152 |
| 24 | 21·805 | 0·0297 | 58 | 131·500 | 0·17866 | 92 | 566·95 | 0·77026 |
| 25 | 23·090 | 0·0314 | 59 | 137·940 | 0·18736 | 93 | 588·74 | 0·79986 |
| 26 | 24·452 | 0·0334 | 60 | 144·660 | 0·19653 | 94 | 611·18 | 0·83035 |
| 27 | 25·881 | 0·0353 | 61 | 151·700 | 0·20610 | 95 | 634·27 | 0·86172 |
| 28 | 27·390 | 0·0374 | 62 | 158·960 | 0·21586 | 96 | 658·05 | 0·89402 |
| 29 | 29·045 | 0·0396 | 63 | 165·560 | 0·22639 | 97 | 682·59 | 0·92736 |
| 30 | 30·643 | 0·0418 | 64 | 174·470 | 0·23758 | 98 | 707·63 | 0·96138 |
| 31 | 32·410 | 0·0440 | 65 | 182·710 | 0·24823 | 99 | 733·46 | 0·99448 |
| 32 | 34·261 | 0·0465 | 66 | 191·270 | 0·25986 | 100 | 760·00 | 1·03253 |
| 33 | 36·188 | 0·0492 | 67 | 200·180 | 0·27196 | | | |

TABLE II.—OF THE TEMPERATURES OF STEAM FOR TENSIONS FROM 1 TO 50 ATMOSPHERES.

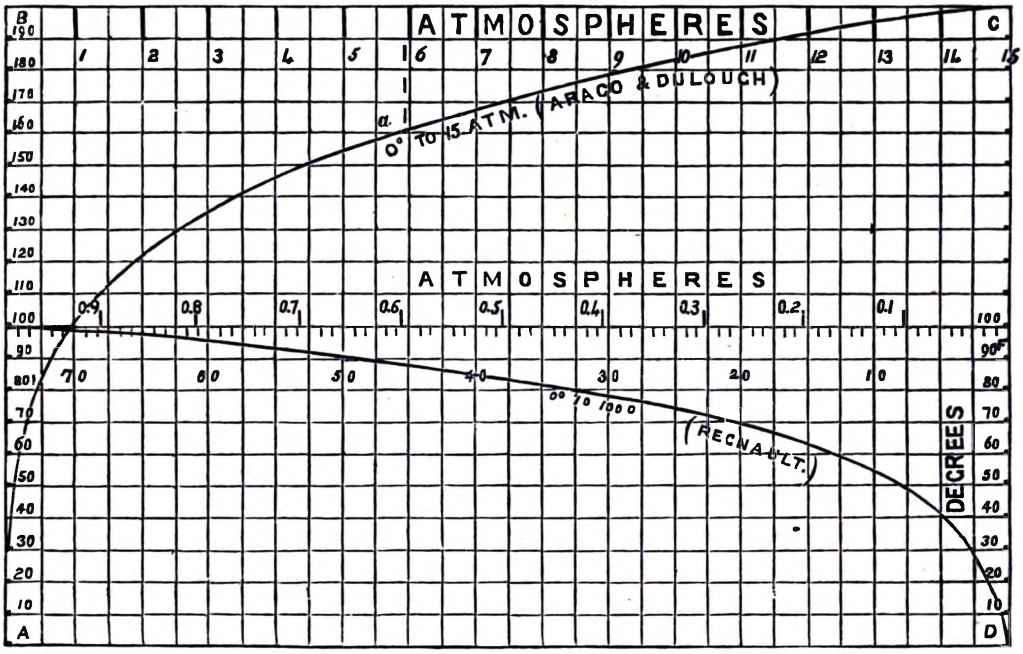
| Elastic Forces expressed in Atmospheres of 76 cents. of mercury. | Corresponding Temperatures given by the Centigrade Mercurial Thermometer. | Pressure in kilogrammes on a centimètre square. | Elastic Forces expressed in Atmospheres of 76 cents. of mercury. | Corresponding Temperatures given by the Centigrade Mercurial Thermometer. | Pressure in kilogrammes on a centimètre square. |
|---|---|---|---|---|---|
| 1 | 100 | 1·033 | 13 | 193·7 | 13·429 |
| 1½ | 112·2 | 1·549 | 14 | 197·19 | 14·462 |
| 2 | 121·4 | 2·066 | 15 | 200·48 | 15·495 |
| 2½ | 128·8 | 2·582 | 16 | 203·60 | 16·528 |
| 3 | 135·1 | 3·099 | 17 | 206·57 | 17·561 |
| 3½ | 140·6 | 3·615 | 18 | 209·4 | 18·594 |
| 4 | 145·4 | 4·132 | 19 | 212·1 | 19·627 |
| 4½ | 149·06 | 4·648 | 20 | 214·7 | 20·660 |
| 5 | 153·08 | 5·165 | 21 | 217·2 | 21·693 |
| 5½ | 156·8 | 5·681 | 22 | 219·6 | 22·726 |
| 6 | 160·2 | 6·198 | 23 | 221·9 | 23·759 |
| 6½ | 163·48 | 6·714 | 24 | 224·2 | 24·792 |
| 7 | 166·5 | 7·231 | 25 | 226·3 | 25·825 |
| 7½ | 169·37 | 7·747 | 30 | 236·2 | 30·990 |
| 8 | 172·1 | 8·264 | 35 | 244·85 | 36·155 |
| 9 | 177·1 | 9·297 | 40 | 252·55 | 41·320 |
| 10 | 181·6 | 10·33 | 45 | 259·52 | 46·485 |
| 11 | 186·03 | 11·363 | 50 | 265·89 | 51·650 |
| 12 | 190· | 12·396 | | | |

TABLE III.—OF THE TEMPERATURES OF STEAM FOR TENSIONS FROM 100 TO 1000 ATMOSPHERES.

| Elastic Forces expressed in Atmospheres. | Corresponding Temperatures. | Pressure in kilos. on a centimètre square. | Elastic Forces expressed in Atmospheres. | Corresponding Temperatures. | Pressure in kilos. on a centimètre square. |
|---|---|---|---|---|---|
| 100 | 311·36 | 103·30 | 600 | 462·71 | 619·8 |
| 200 | 363·58 | 206·60 | 700 | 478·45 | 723·1 |
| 300 | 397·65 | 309·90 | 800 | 492·47 | 826·4 |
| 400 | 423·57 | 413·20 | 900 | 505·16 | 929·7 |
| 500 | 444·70 | 516·50 | 1000 | 516·76 | 1033·0 |

The first idea of a tracing of this nature belongs to M. Clément-Désormes, from whose hints M. Leblanc made a diagram which may be seen in the galleries of the Conservatoire des Arts et Métiers, Paris. The one which we here reproduce, Fig. 852, comprises, in addition, a special tension curve, from 0 to 1 atmosphere, after the table drawn up by M. Regnault.

852.




The principle of the tracing is extremely simple. The vertical scale A B is divided into equal parts indicating a succession of temperatures from 0 to 200 degrees. The horizontal line B C is in like manner divided into equal parts corresponding to pressures expressed in atmospheres. Points have been marked upon the diagram where the vertical and horizontal lines meet, that is, at the intersection of the abscisses and ordinates passing through the temperatures and tensions which face one another in the preceding Tables, and those points united by the curve A C.

A second curve D E has been traced to correspond with the tensions ranging between 0 and 100 degrees, and to enable the results to be more clearly understood by enlarging the scale. Effectually, the total length of the diagram which, on line B C corresponds to 15 atmospheres, represents but one only with respect to the second curve D E, whose graduated scale of tensions is on the line F E, and gives at once the fractions of an atmosphere of 760 millimètres of mercury, and the absolute heights of that liquid expressed in centimètres.

Thus, by this twofold graduation of the scale we see simultaneously to what fraction of an atmosphere steam at a given temperature corresponds, and what is its equivalent in centimètres of mercury.

For instance, let us take a temperature of 70 degrees in the scale D F, and from its intersection *b* with the curve D E draw a vertical line till it meets the scale E F, and we shall find that it answers in that scale to a mercurial height of 23 centimètres and to 0·3 atmospheric pressure.

It is evident that the inverse operation, that is, to find the temperature for a proposed tension, is performed exactly in the same manner, the disposition of the diagram being equally adapted for both purposes.

The construction of these curves is sufficient to show the rapidity with which the tension of steam increases, since, were it proportional, the points of intersection of the lines passing through the temperatures and tensions would be situated on a straight line drawn from A to C. But this is far from being the case, since we see by the Table that the elastic force of steam, at a

temperature of 82 degrees, being equal to 382 millimètres of mercury, or about half an atmosphere; it becomes double or 1 atmosphere at 100 degrees, 2 atmospheres at 121 degrees, 3 atmospheres at 135 degrees, and finally it reaches 24 atmospheres before its temperature has risen to 225 degrees.

Steam is, therefore, a power that requires to be used with great precaution, because, after certain limits, a few degrees of temperature suffice to double its pressure, and may entail serious disaster. This is known to all mechanicians, and should particularly be borne in mind by stokers for their own security.

*Density of Steam.*—The density of steam forms a very important item in the study of engines, since it teaches what are the quantities of water requisite to feed a given motor.

Before giving the mere list of values that correspond to the different densities of steam, according to its tensions and temperatures, some explanation is necessary so as to establish clearly the condition in which it is when a density of any kind is applied.

Steam may be supposed to be in two situations: 1st. Enclosed in a vessel together with a certain quantity of the liquid by which it was generated; 2nd. Enclosed in a vessel of which it fills the entire space without any of the liquid being present.

First condition.—When a vessel contains, at the same time, both liquid and steam, what will happen if the supply of caloric be continued? The water will generate more steam, which will combine with that already formed; but, as the steam occupies a much greater space than the water that has been vaporized, the result will be that, since the primitive volume is only augmented by an imperceptible quantity, its pressure will notably increase, and in a manner analogous to that of a gas when condensed into a given capacity. This effect is further enhanced by the tendency of the first-formed steam to expand on account of the elevation of temperature.

Second condition.—If a vessel, containing steam but no liquid, be subjected to an increase of temperature, the steam will make an effort to expand like a permanent gas, and its tension will increase in the same proportion. Only, in this latter case, the progression of the elastic forces will not be so rapid as in the former, because it results only from the tendency to expansion, which, within certain limits, is proportional to the increased temperature.

Consequences.—Under the first of these two conditions, where the space occupied by the steam, though remaining perceptibly unaltered, is gradually charged with fresh quantities of vaporized water as the temperature and tension increase, it is evident that the density of that steam must vary also, which is not the case under the second condition, where it tends only to expand, but receives no additional charge. The peculiar density of steam is derived, therefore, from the first condition, wherein each new tension corresponds to fresh quantities of vaporized water.

We are indebted to Gay-Lussac for the most complete notions on this subject. The experimental researches made by that illustrious savant enabled him to construct a formula by the aid of which he calculated a table of densities, taking those by MM. Arago and Dulong, touching the relation between temperature and tension, as the base of his operations.

In order thoroughly to understand the application of densities, it must be remembered,

1st. That the said densities correspond to the volumes occupied by the steam when at its maximum of elastic force, after which any mechanical compression would cause it to return to the liquid state;

2nd. That a given weight of steam is exactly equal to that of the water whence it was formed.

TABLE I.—OF THE DENSITIES AND VOLUMES OF STEAM AT ITS MAXIMUM OF ELASTIC FORCE, FROM 0 TO 100 DEGREES.

The density of water at 0° being taken as unity.

| Temperature. | Tension in millimètres. | Density. | Volume. | Temperature. | Tension in millimètres. | Density. | Volume |
|---|---|---|---|---|---|---|---|
| 0 | 5·059 | 0·00000540 | 182323 | 23 | 20·577 | 2021 | 49487 |
| 1 | 5·393 | 573 | 174495 | 24 | 21·805 | 2133 | 46877 |
| 2 | 5·748 | 609 | 164332 | 25 | 23·090 | 0 00002252 | 44411 |
| 3 | 6·123 | 646 | 154342 | 26 | 24·452 | 2376 | 42084 |
| 4 | 6·523 | 686 | 145886 | 27 | 25·881 | 2507 | 39895 |
| 5 | 6·947 | 727 | 137488 | 28 | 27·390 | 2643 | 37838 |
| 6 | 7·396 | 772 | 129587 | 29 | 29·045 | 2794 | 35796 |
| 7 | 7·871 | 818 | 122241 | 30 | 30·643 | 2938 | 34041 |
| 8 | 8·375 | 867 | 115305 | 31 | 32·410 | 3097 | 32291 |
| 9 | 8·909 | 919 | 108790 | 32 | 34·261 | 3263 | 30650 |
| 10 | 9·475 | 0·00000974 | 102670 | 33 | 36·188 | 3435 | 29112 |
| 11 | 10·074 | 0·00001032 | 99202 | 34 | 38·254 | 3619 | 27636 |
| 12 | 10·707 | 1092 | 91564 | 35 | 40·404 | 3809 | 26253 |
| 13 | 11·378 | 1157 | 86426 | 36 | 42·743 | 4017 | 24897 |
| 14 | 12·087 | 1224 | 81686 | 37 | 45·038 | 4219 | 23704 |
| 15 | 12·837 | 1299 | 77008 | 38 | 47·579 | 0·00001442 | 22513 |
| 16 | 13·630 | 1372 | 72913 | 39 | 50·147 | 4666 | 21429 |
| 17 | 14·468 | 1451 | 68923 | 40 | 52·998 | 4916 | 20343 |
| 18 | 15·353 | 1534 | 65201 | 41 | 55·772 | 5156 | 19396 |
| 19 | 16·288 | 1622 | 61654 | 42 | 58·792 | 5418 | 18459 |
| 20 | 17·314 | 1718 | 58224 | 43 | 61·958 | 5691 | 17572 |
| 21 | 18·317 | 1811 | 55206 | 44 | 65·627 | 6023 | 16805 |
| 22 | 19·417 | 1914 | 52260 | 45 | 68·751 | 6274 | 15938 |

TABLE I.—OF THE DENSITIES AND VOLUMES OF STEAM, &c.—*continued.*

| Temperature. | Tension in millimètres. | Density. | Volume. | Temperature. | Tension in millimètres. | Density. | Volume. |
|---|---|---|---|---|---|---|---|
| 46 | 72·393 | 6585 | 15185 | 74 | 273·030 | 22794 | 4387 |
| 47 | 76·205 | 6910 | 14472 | 75 | 285·070 | 23789 | 4204 |
| 48 | 80·195 | 7242 | 13809 | 76 | 297·570 | 24702 | 4048 |
| 49 | 84·370 | 7602 | 13154 | 77 | 310·490 | 25699 | 3891 |
| 50 | 88·742 | 0·00007970 | 12546 | 78 | 323·890 | 26739 | 3741 |
| 51 | 93·304 | 0·00008354 | 11971 | 79 | 337·760 | 27789 | 3599 |
| 52 | 98·075 | 8753 | 11424 | 80 | 352·080 | 0·00028889 | 3462 |
| 53 | 103·060 | 9174 | 10901 | 81 | 367·000 | 30025 | 3331 |
| 54 | 108·270 | 0·00009606 | 10410 | 82 | 382·380 | 31195 | 3206 |
| 55 | 113·710 | 0·00010054 | 9946 | 83 | 398·280 | 32399 | 3087 |
| 56 | 119·390 | 10525 | 9501 | 84 | 414·730 | 33637 | 2973 |
| 57 | 125·310 | 11011 | 9082 | 85 | 431·710 | 34916 | 2864 |
| 58 | 131·500 | 11523 | 8680 | 86 | 449·260 | 36237 | 2760 |
| 59 | 137·940 | 12044 | 8303 | 87 | 467·380 | 37590 | 2660 |
| 60 | 144·660 | 12599 | 7937 | 88 | 486·090 | 38984 | 2565 |
| 61 | 151·700 | 13179 | 7594 | 89 | 505·380 | 40417 | 2474 |
| 62 | 158·960 | 13760 | 7267 | 90 | 525·280 | 41891 | 2387 |
| 63 | 166·560 | 14374 | 6957 | 91 | 545·800 | 0·00043405 | 2304 |
| 64 | 174·470 | 15010 | 6662 | 92 | 566·950 | 44956 | 2224 |
| 65 | 182·710 | 15668 | 6382 | 93 | 588·740 | 46556 | 2148 |
| 66 | 191·270 | 16356 | 6114 | 94 | 611·180 | 48201 | 2075 |
| 67 | 200·180 | 17060 | 5860 | 95 | 634·270 | 49886 | 2005 |
| 68 | 209·440 | 17797 | 5619 | 96 | 658·050 | 51613 | 1938 |
| 69 | 219·060 | 18566 | 5386 | 97 | 682·590 | 53388 | 1873 |
| 70 | 229·070 | 19355 | 5167 | 98 | 707·630 | 55191 | 1812 |
| 71 | 239·450 | 20174 | 4957 | 99 | 733·460 | 57055 | 1751 |
| 72 | 250·230 | 21013 | 4759 | 100 | 760·000 | 0·00058955 | 1696 |
| 73 | 261·430 | 21889 | 4569 | | | | |

TABLE II.—THE DENSITIES AND VOLUMES OF STEAM FROM 1 TO 50 ATMOSPHERES.

| Temperature. | Elastic Force expressed in Atmospheres. | Density. | Volume. | Temperature. | Elastic Force expressed in Atmospheres. | Density. | Volume. |
|---|---|---|---|---|---|---|---|
| 100 | 1 | 0·0005895 | 1696 | 193·7 | 13 | 0·006107 | 163·74 |
| 112·2 | 1·5 | 0·0008563 | 1167·8 | 197·2 | 14 | 0·006527 | 153·10 |
| 121·4 | 2 | 0·0011147 | 897·9 | 200·5 | 15 | 0·006944 | 144·00 |
| 128·8 | 2·5 | 0·0013673 | 731·39 | 203·6 | 16 | 0·007359 | 135·90 |
| 135·1 | 3 | 0·0016150 | 619·19 | 206·6 | 17 | 0·007769 | 128·71 |
| 140·6 | 3·5 | 0·0018589 | 537·96 | 209·4 | 18 | 0·008178 | 122·28 |
| 145·4 | 4 | 0·0020997 | 476·26 | 212·1 | 19 | 0·008583 | 116·51 |
| 149·1 | 4·5 | 0·0023410 | 427·18 | 214·7 | 20 | 0·008986 | 111·28 |
| 153·1 | 5 | 0·0025763 | 388·16 | 217·2 | 21 | 0·009387 | 106·53 |
| 156·8 | 5·5 | 0·0028091 | 355·99 | 219·6 | 22 | 0·009785 | 102·19 |
| 160·2 | 6 | 0·0030402 | 328·93 | 221·9 | 23 | 0·010182 | 98·21 |
| 163·5 | 6·5 | 0·0032683 | 305·98 | 224·2 | 24 | 0·010575 | 94·56 |
| 166·5 | 7 | 0·0034981 | 286·12 | 226·3 | 25 | 0·010968 | 91·17 |
| 169·4 | 7·5 | 0·0037217 | 268·82 | 236·2 | 30 | 0·012903 | 77·50 |
| 172·1 | 8 | 0·0039434 | 253·59 | 244·8 | 35 | 0·014663 | 68·20 |
| 177·1 | 9 | 0·0043865 | 227·98 | 252·5 | 40 | 0·016644 | 60·08 |
| 181·6 | 10 | 0·0048226 | 207·36 | 259·5 | 45 | 0·018497 | 54·06 |
| 186·0 | 11 | 0·0052557 | 190·27 | 265·9 | 50 | 0·020306 | 49·31 |
| 190·0 | 12 | 0·0056834 | 175·96 | | | | |

TABLE III.—THE DENSITIES AND VOLUMES OF STEAM FROM 100 TO 1000 ATMOSPHERES.

| Temperature. | Elastic Force expressed in Atmospheres. | Density. | Volume. | Temperature. | Elastic Force expressed in Atmospheres. | Density. | Volume. |
|---|---|---|---|---|---|---|---|
| 311·36 | 100 | 0·037417 | 26·72 | 462·71 | 600 | 0·17791 | 5·621 |
| 363·58 | 200 | 0·068635 | 14·570 | 478·45 | 700 | 0·20318 | 4·921 |
| 397·65 | 300 | 0·097671 | 10·238 | 492·47 | 800 | 0·2279 | 4·387 |
| 423·57 | 400 | 0·12534 | 7·978 | 505·16 | 900 | 0·2522 | 3·965 |
| 444·70 | 500 | 0·15202 | 6·578 | 516·76 | 1000 | 0·276 | 3·622 |

The use of these Tables is easily understood. For the present, let it be observed that, as all the values have not been derived from actual experiments, it is possible that some may not be in strict accord with real facts; but, as they set forth this property, that the density of steam increases with the tension and temperature, we conclude therefrom that, with a temperature sufficiently high, it is probable that it would equal that of water; that is to say, that a certain quantity of water might pass to the state of steam without augmentation of volume; "in which case it would have," says M. Pouillet, in his excellent 'Treatise on Physics,' "a tension of several hundreds—perhaps of several thousands—of atmospheres." We learn from that savant that an experiment has been made by M. Cagnard de la Tour demonstrating a fact that seems to be an approach towards that hypothetical result. It is thus: a strong glass tube is filled to be a quarter of its capacity with water; this done, it is exhausted of air and sealed hermetically. It is then exposed to a gradually-increasing temperature, when, on arriving at a certain temperature, the water seems to vanish altogether, and the tube appears empty; but, on slightly cooling, the liquid returns almost suddenly . . . ; this effect is produced at a temperature nearly equal to that which causes the fusion of zinc, or 360 degrees centigrade. In other terms, the whole of the water vaporizes in a space only four times its volume!

*The Ebullition of Water.*—In order that the fundamental properties of the formation of steam may be well understood, it is necessary that the phenomenon of ebullition be fully explained: but, as that explanation would not have been intelligible without a portion of the preceding notions, we have been compelled to give them first.

Everybody knows what takes place when we heat, during a sufficient length of time, a vessel containing water in free communication with the atmosphere. At first, a vapour is seen to rise that seems to emanate from the surface of the liquid, getting more and more intense as the water becomes warmer. Then a tremor of the surface is produced, accompanied by a peculiar noise which has been called *the singing* of the liquid; and finally bubbles, similar to air-bubbles, form in that part of the vessel that is nearest to the fire, then rise to the surface, where they burst, giving forth fresh vapour. Those bubbles are nothing else than certain molecules of the liquid being transformed into steam, and which, meeting with an equal pressure on all sides, from the water itself and from the atmosphere, offers an equal resistance in return, and so assume the spherical form in which they are seen to ascend.

Now, an immediate consequence may be drawn from the simple observation of this fact, which is, that the pressure of the steam, in order that it may form these bubbles, must be greater than that of the liquid mass and of the atmosphere acting upon its surface. Consequently, if that pressure, which we will designate as that of ebullition, corresponds to an ascertained fixed temperature, it is evident that—the atmospheric pressure remaining unchanged—the liquid must always reach that temperature before the ebullition can manifest itself.

That, in fact, is rigidly what takes place. Every time that water boils in the open air, its temperature is always the same with a uniform barometrical pressure. If it has been found that water at 100 degrees centigrade generates steam under the atmospheric pressure, it is simply because we have chosen to mark the hundredth degree of the centigrade thermometer under a barometrical pressure of 76 centimètres of mercury.

The ebullition of a liquid can, therefore, only take place so long as the steam it is capable of emitting balances the united pressures of the ambient medium wherein it is situated, and of its own mass or load above the surface heated.

This definition of the phenomenon suffices to show that the degree of temperature at which the ebullition of a liquid may be produced is variable, and changes according to the pressure of the medium, since vaporization takes place at any degree. If a perfect vacuum could be established, and water at the freezing-point placed in it, it would immediately begin to boil; but, in practice, it is never perfect, so that ebullition only takes place at a few degrees above zero. On the summit of Mont Blanc, where the atmospheric pressure is reduced from 760 millimètres to about 417, measuring by the barometer from the level of the sea, water would begin to boil at the temperature of 84 degrees, at which, as we have shown in one of the foregoing Tables, page 415, the elastic force of steam is equal to 414 millimètres, or a little more than half the pressure of an atmosphere.

Finally, the greater the pressure to which water is subjected, the greater is its heat when boiling, and *vice versâ;* that is why the temperature of boiling water is higher in a valley than on a mountain. Let us add, by way of corollary, that, the conditions being similar, the expansive force of the steam of all liquids is equal at the moment of ebullition. This is an axiom, since the very fact of the ebullition sufficiently testifies that the elastic force of the steam has become equal to that of the medium in which it has formed.

*Fixity of the Temperature at Boiling-point.*—At whatsoever temperature ebullition may be produced, so long as it continues that temperature remains unchanged; in other words, the liquid ceases to become heated the instant it begins to boil, always provided that the pressure of the medium undergoes no alteration. This fact is easily explained if we reflect that, as the liquid has acquired a temperature at which it can no longer subsist without change of state, all fresh quantities of caloric supplied are absorbed by the formation of steam. Therefore, under the ordinary conditions in which we boil water, it acquires, when pure, a temperature of 100 degrees, and retains it without variation. In reality, it would only reach that temperature on a level with the sea; but in most European towns, which are necessarily higher, it does not exceed 99·8 degrees. This difference is unimportant with regard to the point under consideration.

In order to increase the temperature, it would be necessary to create an artificial atmosphere of proportionally greater pressure than the ambient one, which is precisely what is obtained, in the case of steam-engines, by hermetically closing the vessel that contains the liquid. The steam that is disengaged then becomes compressed, and prevents the generation of further quantities except under a higher temperature. That is what took place in the experiments made by

MM. Arago and Dulong to which we have previously alluded. We may add that, if the vessel in which the water is vaporized remains closed, without any expenditure of steam, the ebullition cannot even be effected, as the pressure, increasing every moment, prevents the formation of the bubbles.

*Papin's Saucepan.*—To obtain an experimental demonstration of this phenomenon, the apparatus known by the name of *Papin's Saucepan*, after its inventor, may be used. That apparatus consists simply of a vessel A, Fig. 853, made of metal, and having very great power of resistance. It is perfectly closed, with the exception of a small hole in the lid, fitted with a valve which a lever B, disposed like a Roman balance, keeps securely in its place. This arrangement is well known, being none other than that of the actual safety-valve, which is composed of the lever whose pressure is exerted upon the valve *a*, situated between its articulated attachment and the weight C at its other extremity. The valve, therefore, can only rise out of its place by overcoming the resistance opposed by the lever in virtue of its load and the ratio of the two arms.

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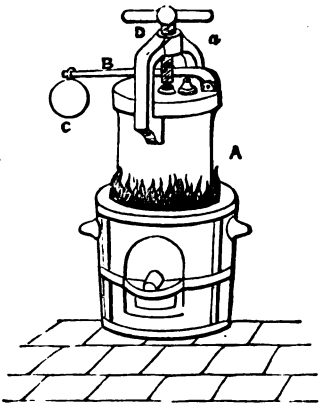


The lid of the vessel A is also very firmly secured by means of a fastening D, bent in the form of an arc, and supplied with a pressure-screw, by the aid of which the lid is made to press hermetically upon the edge of the vase, care having been taken to insert between the two a round of soft metal for that purpose.

The apparatus being thus constructed so as to resist a strong internal pressure, it is filled to about one-third of its capacity with water, and placed over a fire after being carefully closed. Gradually the temperature of the water begins to increase; but, as the steam that forms is unable to escape, except upon the condition that its pressure is capable of opening the valve, it becomes compressed, and soon the ebullition is unable to proceed.

If, at the moment when the internal pressure appears to reach that point where it is likely to raise the valve, the latter be opened, or a cock attached to the lid be suddenly turned on, the ebullition immediately manifests itself, and the steam escapes with impetuosity in the form of a jet which may reach a height of eight or ten mètres, according to the amount of pressure within the vessel. The liquid cools to 100 degrees, and soon the whole of it goes off in steam, provided that the action of the fire be continued sufficiently long, and that the valve or cock be left open.

The pressures to which the steam may reach under this condition are very considerable, and depend, moreover, upon the weight wherewith the valve is loaded.

Without enlarging upon the details that will be given later touching this important apparatus, we may at once make a few remarks as to the conditions that have to be fulfilled in order that it may meet a given pressure.

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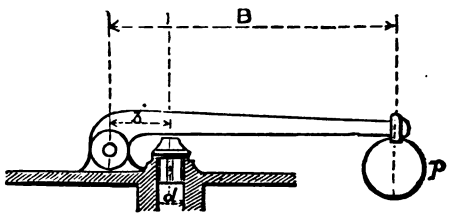


Fig. 854 shows the arrangement of the safety-valve, where we will call B the distance from the centre of articulation to the centre of the weight, or the long arm of the lever; *b*, the distance from the same point to the centre of the valve, or the short arm of the lever; *d*, the diameter of the orifice closed by the valve; *p*, the intensity of the weight suspended from the lever; P, the total upward pressure exerted by the steam upon the valve over a circular surface whose diameter is *d*.

We first of all find, by the arrangement of the lever, and in accordance with its general properties, that the downward pressure P′ which it exerts upon the valve is equal to $P' = p \times \frac{B}{b}$, supposing, for the moment, the lever itself to be without weight.

In order that the valve may be kept in its place until the given pressure has been attained, it is necessary that the efforts P′ and P be equal. But the effort P is always easily known, for it results from the said pressure and the diameter of the orifice *d*, whose area may be calculated.

Consequently, the operation resolves itself into finding the effort P, by means of the conditions laid down, and substituting it for P′ in the preceding equation, which will enable us to calculate one of the three dimensions *p*, B, or *b*, the two others being fixed *a priori*.

Example.—Be it required to find the conditions of a valve having to bear a pressure of 20 atmospheres.

Let us suppose the diameter *d* of the orifice to be equal to 1 centimètre.
" " long arm B of the lever " 30 "
" " short arm *d* of the lever " 2 "
what will be the intensity of the weight?

A pressure of 20 atmospheres represents an effort equal to $1^k \cdot 0333 \times 20 = 20^k \cdot 666$ for every centimètre square; consequently, the diameter of the valve being 1 centimètre, the pressure exerted upon it will be equal to the product of the corresponding section, in square centimètres, by the above pressure, from which pressure we must deduct that necessarily exerted downwards by the external atmosphere, and which is equal to 1.

We therefore have for the effective effort P,

$$P = (20 - 1)\, 1 \cdot 0333 \times 0 \cdot 7854 \times 1^2 = 15 \cdot 42 \text{ kilogrammes.}$$

From this it results that adapting the preceding relation with $p$ for the unknown quantity, we shall have for its value, $p = P'$ or $P \frac{b}{B} = 15^{k} \cdot 42 \times \frac{2}{30} = 1 \cdot 028$ kilogramme.

In conclusion, it will be observed that the displacement of the weight upon the lever would be sufficient to alter the conditions of the problem, and consequently the result, since the arms of the lever would no longer bear the same ratio to one another.

The valve, then, is the only cause that limits the pressure which the steam may acquire in the experiment of Papin's saucepan; apart, of course, from the capability of resistance of the vessel itself. By this method pressures of 40 and even 50 atmospheres have been obtained, that is to say, steam exerting the enormous effort of 50 kilogrammes on the square centimètre, or 500,000 kilogrammes on the square mètre.

*Influence of Substances in Dissolution upon the Temperature of the Boiling-point.*—Among the several causes that intervene sometimes to modify by a few degrees the ebullition of water, the pressure of the medium remaining the same, we may cite salts and other substances in dissolution, which retard the boiling-point to a certain extent, according to the degree of saturation. Thus, water saturated with sea-salt is hotter at the moment of ebullition than when it is pure, or even when it contains merely bodies in suspension that are not chemically combined with it.

Considered from the purely practical point of view that occupies us at present, this phenomenon has, however, no very great importance; since, supposing the saturation to be complete, which is rarely the case with water used for steam-engines, the temperature of the boiling-point is increased only by 9 degrees. Marine engines, and certain permanent engines situated near the sea, are fed, however, from its waters, which contain salt in large proportions. But, in this case, the principal objection is not the alteration of temperature, but the danger of explosion from the deposits that would form were the generator not kept constantly clean.

*Method of Vaporizing a Liquid that contains Foreign Matter.*—When a liquid containing foreign matter, in a state of mixture, but without chemical combination, is subjected to heat, the vaporization takes place in succession for each of the substances forming the mixture, and in the order of temperature that corresponds with its respective boiling-point.

If, for instance, we expose water containing substances more volatile than itself to the action of heat, those substances will be liberated first, while the mass of the liquid remains at the temperature that suits their ebullition; then, when they have disappeared, the temperature of the water will begin to rise till it reaches the boiling-point.

In the opposite case, where the substances are less volatile than water, the latter vaporizes first, at the temperature suited to its ebullition, under reserve of the slight modification that may result from the mixture or the dissolution, as above mentioned.

This fact will be very easily understood by observing that so soon as the liquid mass has acquired the temperature necessary for the ebullition of the most volatile of the liquids composing the mixture, in order that the latter may be vaporized, it absorbs all the fresh quantities of heat supplied, and which are thus prevented co-operating in elevating the temperature of the entire mass.

Therefore is it that vaporized water is considered pure, whatever may have been the foreign matter held in solution, since this last either has or will disappear, but never at the same time as the water.

Such are at least the practical conditions we have to take into consideration regarding the subject that occupies our present attention. Steam-engines present constant examples of the principle whereby water is isolated, by vaporization, from the substances mixed with it or held in solution. Everybody, indeed, is aware of the fact of the incrustation of steam-boilers by the sedimentary deposits resulting from the continued abandonment by the water, as it vaporizes, of the various calcareous and saline substances which it contains in different proportions. The feeding of boilers with sea-water gives rise to considerable deposits of sea-salt, separated from the water at the moment of vaporization. This is what gives rise to those repeated cleansings so indispensable for the avoidance of accidents.

*Condensation of Steam.*—What is called the condensation of steam is its return to the liquid state. We have already seen that a slight compression beyond its maximum of elastic force is sufficient to restore it to that state, either in part or in totality, according as the compression is momentary, or continued until the volume of fluid is reduced to that which it occupied when in the liquid form; of course, without any addition of heat. But in engines, it is not after this fashion, which is in reality *the liquefaction of steam*, that its destruction is effected.

Condensation consists in *cooling* the steam by means of a certain quantity of cold water that takes up the heat that maintained it in the condition of an elastic fluid, yielding as result an amount of warm water, the steam from which has an elastic force very considerably less than that which has been destroyed, and may be rendered as feeble as can be desired, according to the volume and temperature of the cold water added.

This property of condensation is of the highest importance, since it enables us to get rid, almost instantaneously, of the potent fluid that has just produced an effect, but would afterwards neutralize it if allowed to retain its expansive properties. The only thing needed to render atmospheric air and other gases motive agents susceptible of replacing steam with advantage, is the capability of easy condensation, since they exist naturally in the state of elastic fluids under the ordinary temperature.

It will be shown shortly how powerful engines have been constructed, with the atmospheric pressure for motive agent, and using steam as an auxiliary power, but one possessing the valuable property of being destroyed, leaving a vacuum wherein the surrounding atmosphere can act with irresistible force.

*Absorption.*—We will conclude this outline of the phenomenon of condensation by citing an

experiment known to physicists under the name of *absorption*, designed, in the first place, to demonstrate the faculty we possess of creating a vacuum by means of the condensation of steam; and, in the next, to caution us against the accidents that may result from that selfsame property.

In chemical experiments, and in many industrial operations, an apparatus is used analogous in arrangement to that represented in Fig. 855. This arrangement consists of a closed receiver A, placed over a furnace B, and containing a liquid that has to boil; then a pipe D that starts from the receiver and, descending, plunges into a vessel C, containing some cold liquid, such as water, through which the steam disengaged from the receiver A has to pass.

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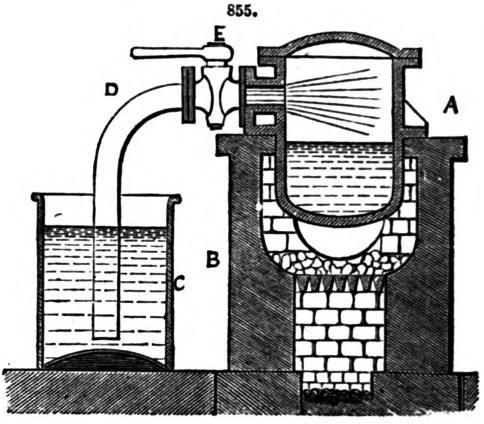


As soon as ever the ebullition commences, the steam that is generated expels, by degrees, the air contained in the apparatus, and forces it to escape by the pipe D, driving the liquid before it, whose level is necessarily the same in the tube and in the vessel; and finally passes through the tube itself, rising, in the form of bubbles, through the water contained in the open vessel. The air being completely expelled, the apparatus is now filled with steam only. Things being in this state, if we extinguish the fire and continue to keep a free communication between the two vessels through the pipe D, the steam will gradually cool, losing a portion of its elastic force. But, as that elastic force was the only thing that balanced the atmospheric pressure plus that of the height of the water in the vessel C, the excess of that external pressure begins to manifest itself by the rising of the water in the pipe D. As the cooling goes on, the pressure of the steam continues to diminish and the water to ascend in the tube till it reaches the top and finally penetrates the body of steam still remaining in the boiler A. At this juncture the whole of the steam is soon completely destroyed and a vacuum is created, that is to say, an absence of all expansible fluid. We then see the water continue rising, but this time with impetuosity, until the entire apparatus is filled, if the water in the vessel C be sufficient for the purpose.

This effect, so simple to understand, is produced every time that a capacity containing steam is placed in communication with a reservoir of liquid with a sufficient pressure, and that the steam is destroyed by condensation—on condition, however, that the pressure of the column of water in the tube, if full, exceed not that supported by the liquid in the open vessel. In the foregoing experiment it is certain that if the distance between the level of the water in the vase C and the horizontal portion of the pipe D had exceeded, vertically, ten mètres, the water in the reservoir could never have entered the boiler, and the vacuum would have remained.

Therefore, if absorption is a thing to be feared, a vacuum is not less so, since the atmospheric pressure, that has the power of raising the water from the lower to the upper reservoir, may likewise burst in the latter, if it be exhausted and have not sufficient strength of resistance. Whenever there is danger of such an accident occurring, it is remedied by means of a small valve, opening inwards, which allows the air to re-enter the apparatus. To prevent absorption, a cock E may be employed, which should be closed before the condensation of the steam.

We see, then, that the condensation of steam is the means of creating a vacuum and raising almost any volume of liquid to a height corresponding to the atmospheric pressure, and which varies according to the density of the liquid used. Effectually, what we have been signalizing as accidents, constitute, in many cases, most valuable resources in their practical application.

*Calorific Action in the Formation of Steam.*—Caloric, or heat, is the chief agent, or, to express ourselves more appropriately, the sole apparent cause of the phenomena of dilatation and the change of state that bodies undergo; for, by penetrating the mass of constitutive molecules, it compels them to separate, and widens the interstices that seem naturally to exist between them. This external fact might be defined by saying that heat repulses the molecules of a body from each other in order to make room for itself, and establish an equilibrium between its own intensity and that of the medium or space occupied by the mass of the body; and that the result of this intervention is an effort of repulsion equal and opposed to the cohesive force of the molecules themselves.

We conclude, from this definition as well as from the observed fact, that the greater the amount of heat so much greater is the effect of repulsion. Finally, this distension of the molecules by an excessive quantity of heat, after producing simple expansion or augmentation of volume, results in a change of state; that is to say, that from solid a body becomes liquid, and from liquid it passes into the gaseous state or steam.

It must not, however, be supposed, because this second change, as regards liquids, takes place in vacuum without any apparent intervention of heat, that that intervention is wanting. It would be an error. The action of caloric is quite as real as in any other mode of forming steam; and, as we have already remarked, the only result of a vacuum is to give rise instantaneously to what would have taken place but slowly in the open air. The atmospheric pressure is simply an effort to be overcome by larger quantities of heat in order to create steam beneath its influence. As to the heat necessary to produce the phenomenon in a barometer, it is taken from the liquid mass and from the instrument itself, instead of being supplied by fire.

There is, therefore, no exception as regards the formation of steam. Whatever method we make use of in order to produce it, caloric always intervenes, and with the same intensity, when the tensions are the same.

We only repeat here what has already been fully demonstrated in the preceding sections. We now pass on to the

*Mechanical Power of Steam.*—The reason why steam is used, in preference to permanent gases, to produce motive labour, is because of the facilities we have of quickly destroying its power; or, in general, of giving it a tension superior to that of the medium in which the motor works to which it is applied. For, the action of expansion being the same in all cases, such gases could be employed as motive force just as well as steam were it equally possible to increase or lessen their pressure without expenditure of mechanical force

It is true that engines have been constructed worked by atmospheric air heated; such a process is quite practicable; but, besides the question of economy, it is much more difficult to deprive air of its heat after doing its work than it is to destroy steam by condensation. So that, up to the present, the latter remains master of the field. We shall now endeavour, therefore, to explain the mechanical properties of steam, as applied to motion, observing, at the same time, that the identical reasoning holds good in the case of any permanent gas.

*Work Done with Full Pressure.*—It has been seen that, when steam is let off from a receiver or reservoir of any kind, it escapes with an energy the intensity of which depends upon its own tension and that of the medium in which the flow takes place. The escape is, indeed, the consequence of the pressure exerted by the steam upon all points of the receiver containing it, and particularly upon the parts surrounding the orifice.

In order to transform this property into motive labour, let us suppose the following experiment:

A vessel, A, Fig. 856, full of steam that can be continuously renewed with a tension greater than that of the ambient medium, is furnished with a vertical tube B of indefinite length. The latter contains a column of mercury resting upon a small piston *a*, while a stop-cock C enables the communication between it and the reservoir to be cut off.

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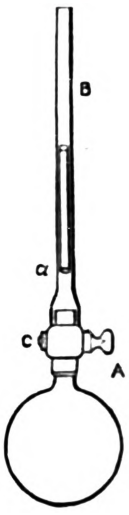



When the stop-cock is closed, the column of mercury and its piston or diaphragm are at the lower end of the tube, and rest upon the cock; but, if we come to open this last, the pressure of the steam will exert itself beneath the mercury and endeavour to raise it in order to make its escape. The result of this action will be different, however, according to the reciprocal situation of the elements.

In the first place, if the column of mercury, together with the external pressure which it has to bear, be equal or superior to the pressure exerted by the steam at its base, the column of mercury will remain stationary, and there will be no escape of steam; the mercurial column fully representing the resistance opposed to the expansion of the steam by the sides of the vessel.

But if the pressure of the steam be the greater of the two, the column of mercury will rise in the tube with an acceleration uniformly increasing till it becomes equal to that of the steam, beyond which it evidently cannot go.

Consequently, by choosing this point of uniform velocity, we have not only the representation, but the actual measurement of a certain mechanical work performed, for we have a weight—that of the column of mercury—raised and moving with a fixed velocity in a unity of time. Thus the simple pressure of the steam is transformed into a real dynamical effect. Now it is not at all necessary to suppose that the steam has acquired the full velocity due to its tension, for it may raise the weight with a uniform velocity as slow as can possibly be imagined. To conceive this, let us examine what would occur in the case under consideration.

In the first place, the column of mercury, being inferior in weight to the pressure of the steam, will rise with an increasing acceleration, whose more or less rapid progression will depend upon the greater or less excess of the power over the resistance.

But, if we re-establish the equilibrium at any given point of that progression by the addition of a small quantity of mercury, the acceleration will cease, and the velocity will preserve the uniform value it had at the moment of that re-establishment.

From this observation we may say, as in the case of hydraulic motors, that

*In an engine, whose motion is uniform, the moving forces and the resistances are in perfect equilibrium.*

The same experiment shows, likewise, the excess of force expended to overcome the inertia of a body, and make it acquire a uniform velocity in a given time.

To sum up the foregoing definition, the work done by steam is also measured by a weight, in kilogrammes, moving in a straight line at the rate of a certain uniform velocity, expressed in mètres, in a second of time.

The above experiment furnishes us, then, with the exact terms of the problem, wherein the weight of mercury raised, plus the ambient pressure it supports, represents the resistance overcome, and which must be equal to the pressure of the steam at the base of the column at the moment that uniform velocity takes place.

Therefore, if that column weighs, atmospheric pressure included, 2 kilogrammes, for instance, with an area at the base equal to 1 centimètre, the tension of the steam will have to acquire a similar value for every square centimètre, or, at an approximation, a pressure of about 2 atmospheres.

If the velocity, remaining uniform, were equal to 1 mètre in every second of time, the labour expended would be 2 kilogrammètres. The useful work would be half that quantity, because we suppose the atmospheric pressure to form half the resistance.

Not only is the work done by the effort exerted by steam assimilative to the simple displacement of a weight, but the quantities of steam to be expended may also be measured by the amount of work of which they are capable. In the preceding experiment it is clear that for every mètre which the resistance has been made to travel, a fresh volume of steam, measured by

the section of the tube and that distance, has had to be supplied by the reservoir. Consequently, the volumes of steam expended are exactly proportional to the work done, which itself is expressed by the distance and the intensity of the weight raised, while this latter, again, is represented by the inferior section of the tube and the pressure of the steam thereon. But, on the other hand, as the pressure depends upon the tension of the steam and the area of the section, we conclude that the volume of steam expended to do a given work is inversely proportional to the figure of its unity of effective tension.

Finally, 1 kilogrammètre being the product of 1 kilogramme by 1 mètre, corresponds to an expenditure of steam, with an effective tension of 1 atmosphere, equal to a column 1 mètre in height by 1 centimètre square at the base, barring a fraction: or 0·1 litre. If the effective tension were double, the volume would be one-half less, and so on.

Consequently, the expression for calculating the dynamical unity of volume of steam may be written thus:

$$V = \frac{0{\cdot}1\,k}{1^k{\cdot}0333\,P} = \frac{k}{10^k{\cdot}0333\,P};$$

wherein V represents, in litres, the volume of steam expended;

$k$ „ the quantity of work, expressed in kilogrammètres;

P „ the effective pressure of the steam, that is to say, its excess over that of the medium opposed as resistance, knowing that 1 atmosphere corresponds to an exact pressure of 1·0333 kilogramme on the square centimètre.

Example.—What volume of steam would have to be expended in one second in order to produce 1000 kilogrammètres of work, its effective pressure being equal to 3 atmospheres?

Solution.—We find

$$V = \frac{1000}{10^k{\cdot}333 \times 3} = 32{\cdot}259 \text{ litres.}$$

It is evidently the same with this value as with that which corresponded to the quantity of steam generated for every kilogramme of fuel; it is the theoretical value, or that which answers to the real useful effect; but in practice it varies very much, as we shall see presently, independently even of the method of using steam with expansion. It serves, however, as a general starting-point, which we must not lose sight of.

To show that this result is in conformity with the disposition of the Table that will be seen further on, we will ascertain in a direct manner what amount of work a given volume of steam with a known pressure is able to produce.

By adopting the cubic mètre for unity, it will suffice us to suppose that the base of the tube, in the preceding experiment, has an area of 1 square mètre; this will give 1 cubic mètre of steam generated for every mètre of distance travelled by the resistance. But, as this latter is always in equilibrium with the pressure of the steam, the weight raised will be precisely equal to the tension of the steam multiplied by the base. We shall therefore have 10333 kilogrammes for each atmosphere of pressure, multiplied by 1 mètre; that is, 10333 kilogrammètres as the theoretical work, developed by 1 cubic mètre of steam for every atmosphere of effective pressure.

We must once more observe that this result supposes, as a matter of course, that the initial pressure of the steam remains unaltered during the whole of the time that the work is being done; which is not the case when it is used with expansion, as we shall endeavour presently to explain.

*Work Developed by Expansion.*—From the physical properties recognized in vapours and gases in general, from the beginning, it may readily be imagined what takes place when any space, filled with a definite volume of steam, is enlarged. The said steam, by virtue of its unlimited power of expansion, which makes it tend constantly to augment its dimensions, continues filling the capacity it occupied, in spite of the extension of the latter, and exerting against the sides of the vessel a pressure that diminishes in the inverse ratio of the successive volumes it is made to assume.

This property, the effect of which is entirely analogous to the unbending of a spring that has been compressed and then suddenly allowed to go, is characterized in practice as *the expansion of steam;* and this designation is reserved for engines where steam is used upon that principle.

To convey a general idea of the use of steam with expansion, we need only revert to the experiment last cited, and suppose that the uniform velocity having been obtained, the stop-cock C, Fig. 856, is completely closed, so as to prevent the reservoir furnishing any fresh quantities of steam. That velocity will then be limited to the volume confined in the tube between the stop-cock and the base of the column of mercury raised; if the resistance remained fixed, the motion would be continued for a few moments by virtue of the acquired velocity, but with a uniformly retarded movement, till it became extinct, when the column of mercury would immediately fall, reducing the volume of steam to that which it occupied at the time that the stop-cock was closed.

But, if it were possible gradually to diminish the weight of the mercurial column in the same ratio as the pressure of the steam, which lessens as the space it occupies enlarges, the uniform ascending motion would be maintained, and the steam would still yield work through the agency of its expansive power, weaker and weaker, it is true, but which—were it not for the limit marked by the external resistance of the ambient medium, to which the force of the steam must be superior in order to produce an effect—might be indefinite.

Consequently, over and above the work developed by the free flow of steam from the reservoir, and estimated in the manner already indicated, there is yet a further amount of labour capable of being produced without any extra expenditure of steam; it is, in fact, certain that, in order to draw the greatest possible profit from steam, it should not be relinquished until its pressure has become so weak as to be almost unfit for any useful work.

There now remains to be calculated what are the total quantities of work developed under these

conditions. This it will be easy to do as soon as we have said a few words touching the law discovered by Boyle, commonly called the law of Mariotte, to which we have hitherto only alluded.

*Mariotte's Law.*—When a definite volume of any permanent gas is subjected to different pressures, it is readily perceptible that it diminishes in volume as the pressure increases, and, reciprocally, that the former augments as the latter decreases.

Apart from this first result, which is evident and palpable, it has been ascertained that, the temperatures being equal, the volumes occupied are in a striking manner inversely proportional to the pressures exerted; whence we also naturally deduce that the densities are directly proportional to these same pressures.

This important physical law bears the name of the Abbot Mariotte, a French physicist. Boyle was the first to enunciate it. It has since been verified by the most competent men, such as Arago and Dulong, Faraday, Pouillet, Regnault, and others. These illustrious savants found that Boyle's law suffered some slight variations with certain gases and under considerable pressures; the differences that have been observed by the aid of very delicate operations are not, however, of a nature to disturb the ordinary practical results. We shall therefore admit this law, purely and simply, in order to study the effects of steam in the phenomenon of expansion, where it presents itself as a permanent gas occupying successively different volumes.

Before approaching this subject, let us sum up the law by its numerical representation and by an example.

If we designate by P, the pressure of a gas, or the expression of its elastic force for the unity of surface;

V, its corresponding volume;

$d$, its density;

and by P', V', and $d'$, the same properties under other conditions;

we say $P : P' :: V' : V$; in other words, *the pressures are in the inverse ratio of the volumes.*

We next find $d : d' :: P : P'$ or $d : d' :: V' : V$, that is to say,

*The densities are directly proportional to the pressures, or inversely proportional to the volumes.*

Example.—If we reduce by $\frac{1}{5}$ the volume V = 1 cubic mètre of a gas, whose pressure P = 0·80 mètre of mercury, and whose density $d = 0{\cdot}0012$, what will be the pressure and density P' and $d'$ under the new volume V'?

Solution.—The above relations supply the following:

$$P' = \frac{P \times V}{V'}; \text{ and } d' = \frac{d \times V}{V'}.$$

But, according to the data, the value of the fresh volume is

$$V' = 1^{cm} \times \frac{4}{5} = 0^{cm}{\cdot}8.$$

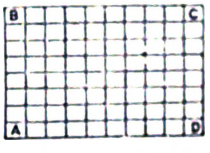
this value we deduce the following ones for the pressure and density:

$$P' = \frac{0{\cdot}80 \times 1^{cm}}{0^{cm}{\cdot}8} = 1^{m}{\cdot}00 \text{ of mercury; and } d' = \frac{0{\cdot}0012 \times 1^{cm}}{0^{cm}{\cdot}8} = 0{\cdot}0015.$$

This law is so simple, that the above indications will certainly suffice to make its application understood. Besides, the two foregoing proportions supply the elements of all the problems that might be proposed. We must only remind our readers that, in order that its application may be correct, it is necessary that the gas subjected to the change of volume shall retain its primitive temperature, otherwise effects of dilatation or contraction are produced that influence and modify individually the result, which is supposed to be due solely to the alteration of volume.

*Calculation of the Total Work done by the Expansion of Steam.*—Since the amount of work done is always expressed by the product of the pressure exerted and the distance travelled by the resistance in the unity of time, balancing that pressure, any quantity of work may then be graphically represented by a surface that can also be measured by the product of two numbers. Effectually, let us suppose a certain effort, expressed in kilogrammes, to be represented upon any given scale by a right line A B, Fig. 857, the divisions upon which indicate precisely so many kilogrammes; and that the distance travelled by the resistance in the unity of time, and under the influence of that effort, be represented by a horizontal line A D, whose divisions are so many mètres or fractions of mètres; it is clear that, by completing the rectangle A B C D, its surface will be the actual measurement of the work, since it is the product of the units in A B by those in A D.

857.




For instance, let A B measure 8 centimètres and represent 8 kilogrammes, while A D, measuring 10 centimètres, represents 10 metres of distance travelled in the unit of time, say 1 second, the amount of work, measured as usual, will be $8 \times 10 = 80$ kilogrammètres.

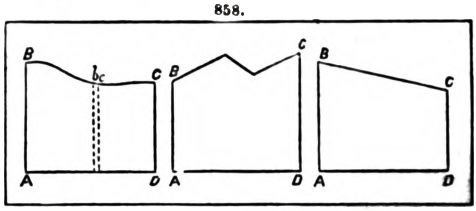
But the surface of the rectangle, estimated, in like manner, by the product of its sides, gives also 80; so that each small rectangle formed by the intersection of the divisional lines represents 1 kilogrammètre.

This fact, very easy of comprehension, being once proved, let us suppose that during the journey the effort varies, though the velocity still remains uniform. It will then happen that the straight line A B, travelling from A B to D C, and which generated a rectangle by the fixity of its value, will no longer possess that fixity, and B C will consequently cease to be a straight line; neither will the figure be a rectangle, but a surface limited by right lines upon three of its sides, and by a broken or curved line upon the fourth; or again by a right line, but not parallel to

the base, if the variation in the resistance follows a certain regular law. We should thus obtain one of the three tracings indicated in the subjoined Fig. 858.

The total amount of work developed for each distance travelled A D, multiplied by the variable resistance, will, however, be none the less accurately represented by the surface of each figure. For such surfaces may be divided into sufficiently small parts, such as *a b c d*, in the direction of the distance travelled, for them to be considered as so many rectangles or portions of work generated by a particular effort which remains fixed during the corresponding time. The surface, then, of every one of those elementary parts will represent the amount of work answering to it; and as the sum of those parts is equivalent to the entire surface of the figure, it naturally follows that this last represents the total amount of work done.

858.




By knowing, then, the law of variation by which an effort is governed during the accomplishment of a certain labour, it will always be easy to reckon the total quantity of work doveloped, since the only thing required is to make a graphic representation thereof and to measure the surface of the figure thus obtained, according to units previously agreed upon as representatives of the efforts and the distance travelled.

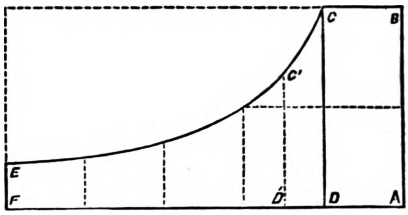
The amount of work accomplished by steam during its expansion falls precisely within the conditions we have just examined. It is a decrescent effort exerted to overcome a resistance which is supposed to diminish in the same ratio in order that uniform velocity may be preserved. As to its law of decrescence, it is admitted that it follows that established by Boyle, as we have already stated, always supposing that the temperature of the steam remains unaltered during the period of expansion.

Let us endeavour, from this, to bring together these principles so as to find the value of the work that would be developed by a determinate volume of steam producing, at first, an amount of labour at full pressure and which can be measured as we have previously shown, and then expanding to a given limit.

By referring back to the experiment, page 424, which was admitted, we were enabled to ascertain the effect produced by a cubic mètre of steam acting with its full initial pressure, and we found that the work thus done was equal to 10333 kilogrammètres for every cubic mètre and for every atmosphere of effective pressure. Moreover, if the distance travelled be equal to 1 mètre, the corresponding pressure will be 10333 kilogrammes. If, now, this work being accomplished, no further steam be supplied, that already introduced and now isolated from its source will occupy gradually-increasing volumes, whence its pressure will successively diminish according to the same decrescent progression as that indicated by Boyle's law. The base of the receiver where the expansion takes place remaining the same, and the volume of steam, therefore, only *lengthening*, the decrescence will apply itself directly to the initial pressure of 10333 kilogrammes.

Let us, consequently, make a graphic representation of the work done at full pressure in the first place by a rectangle A B C D, Fig. 859, of which A B represents the initial pressure 10333, and A D the distance travelled during the performance of the work; then, having extended the base of the rectangle, let us draw lines parallel to A B from each of the points indicating the successive distances run from the moment that the steam was cut off. The value of every one of those vertical lines must be that of the pressure acquired at the end of the corresponding distances; and as these are exactly proportional to the successive volumes of the steam, and as the pressure acquired by the latter at every increase of volume is in the inverse ratio of the proportion which the last volume bears to the first, it will be easy to determine each fresh acquisition of pressure.

859.




At any rate, we get, from the preceding proportion, P : P′ :: V′ : V, the following, C D or A B : C′ D′ :: A D′ : A D.

In other terms, if, for instance, each division of distance travelled or augmentation of volume be $\frac{1}{20}$ of the primitive one A D, we shall have as the successive values of the ordinates similar to C′ D,

$$\text{C D} \times \frac{20}{21}, \frac{20}{22}, \frac{20}{23}, \frac{20}{24}, \frac{20}{25}, \frac{20}{26}, \frac{20}{27}, \text{ and so on,}$$

because the consecutive volumes will be

$$\frac{21}{20}, \frac{22}{20}, \frac{23}{20}, \frac{24}{20}, \frac{25}{20}, \frac{26}{20}, \frac{27}{20}, \text{ and so on.}$$

By uniting, then, the extremities of all the ordinates thus determined, we obtain the complete figure A B C E F, whose surface will represent the total amount of work developed by the primitive volume of steam expanded, till it reaches the augmentation of volume indicated by the extension of the base A F of the figure, which may be continued to any required limit.

If we perform this operation with steam at the unity of pressure, the expansion being the same, the work found by squaring the figure will be proportional to any initial pressure which the steam may possess, because, when the expansion continues unaltered, the base A F is invariable and the heights are proportional to the pressures. But, if we take, as starting-point, a determinate volume of steam, it is clear that the result will likewise be in proportion thereto, because the base

A F is proportional to the primitive volume, and that, the heights being equal, the surface of the figure becomes proportional to its base.

Finally, we ascertain by this process the quantities of work that may be developed by a cubic mètre of steam at a pressure of 1 atmosphere with different degrees of expansion; and when it is wanted to find the work corresponding to another volume and another pressure, it is only necessary to make the product of those different data by the value indicated for 1 cubic mètre. The results thus obtained are completely satisfactory in practice. Only it is indispensable that the apparatus wherein the expansion takes place be so disposed that any external cooling may be avoided, otherwise there would ensue a condensation of the expanded steam that would render the application of Boyle's law incorrect.

Poncelet, who was one of the first to make this theory known, has also calculated a Table giving the quadrature of the initial figure for different expansions, throughout a notable extent.

We here reproduce that Table, to which we shall refer every time we have to calculate the conditions of an engine working with expansion.

TABLE OF THE TOTAL QUANTITIES OF WORK DEVELOPED BY 1 CUBIC METRE OF STEAM UNDER DIFFERENT EXPANSIONS, AND WITH A PRESSURE OF 1 ATMOSPHERE.

| Volume after Expansion. | Quantity of Work Corresponding. | Volume after Expansion. | Quantity of Work Corresponding. | Volume after Expansion. | Quantity of Work Corresponding. | Volume after Expansion. | Quantity of Work Corresponding. |
|---|---|---|---|---|---|---|---|
| c. m. | kgm. | c. m. | kgm. | c. m. | kgm. | c. m. | kgm. |
| 1·00 | 10333 | 1·35 | 13434 | 2·80 | 20973 | 5·50 | 27949 |
| 1·01 | 10436 | 1·40 | 13810 | 2·90 | 21335 | 5·60 | 28135 |
| 1·02 | 10538 | 1·45 | 14173 | 3·00 | 21686 | 5·70 | 28318 |
| 1·03 | 10639 | 1·50 | 14523 | 3·10 | 22024 | 5·80 | 28498 |
| 1·04 | 10739 | 1·55 | 14862 | 3·20 | 22353 | 5·90 | 28674 |
| 1·05 | 10837 | 1·60 | 15190 | 3·30 | 22671 | 6·00 | 28848 |
| 1·06 | 10935 | 1·65 | 15508 | 3·40 | 22079 | 6·25 | 29270 |
| 1·07 | 11032 | 1·70 | 15816 | 3·50 | 23279 | 6·50 | 29675 |
| 1·08 | 11129 | 1·75 | 16116 | 3·60 | 23570 | 6·75 | 30065 |
| 1·09 | 11224 | 1·80 | 16407 | 3·70 | 23853 | 7·00 | 30441 |
| 1·10 | 11318 | 1·85 | 16690 | 3·80 | 24128 | 7·25 | 30804 |
| 1·11 | 11412 | 1·90 | 16966 | 3·90 | 24397 | 7·50 | 31154 |
| 1·12 | 11504 | 1·95 | 17234 | 4·00 | 24658 | 7·75 | 31493 |
| 1·13 | 11596 | 2·00 | 17496 | 4·10 | 24914 | 8·00 | 31820 |
| 1·14 | 11687 | 2·05 | 17751 | 4·20 | 25163 | 8·25 | 32139 |
| 1·15 | 11778 | 2·10 | 18000 | 4·30 | 25406 | 8·50 | 32447 |
| 1·16 | 11867 | 2·15 | 18243 | 4·40 | 25643 | 8·75 | 32747 |
| 1·17 | 11956 | 2·20 | 18481 | 4·50 | 25875 | 9·00 | 33038 |
| 1·18 | 12044 | 2·25 | 18713 | 4·60 | 26103 | 9·25 | 33321 |
| 1·19 | 12131 | 2·30 | 18940 | 4·70 | 26325 | 9·50 | 33597 |
| 1·20 | 12217 | 2·35 | 19162 | 4·80 | 26542 | 9·75 | 33865 |
| 1·21 | 12303 | 2·40 | 19380 | 4·90 | 26755 | 10·00 | 34127 |
| 1·22 | 12388 | 2·45 | 19593 | 5·00 | 26964 | 15·00 | 38317 |
| 1·23 | 12472 | 2·50 | 19802 | 5·10 | 27169 | 20·00 | 41289 |
| 1·24 | 12556 | 2·55 | 20006 | 5·20 | 27369 | 25·00 | 43595 |
| 1·25 | 12639 | 2·60 | 20207 | 5·30 | 27566 | 50·00 | 50758 |
| 1·30 | 13044 | 2·70 | 20597 | 5·40 | 27759 | 100·00 | 57920 |

*Use of the preceding Table.*—The first column of the above Table shows the successive volumes that a cubic mètre of steam may assume by expansion under a pressure of 1 atmosphere, and the second the total quantities of work corresponding thereto, developed before and during expansion. The Table exhibits, also, the great advantage of prolonged expansion.

So that a cubic mètre of steam that only develops 10333 kilogrammètres of work if used without expansion, produces 26964 kilogrammètres when allowed to expand to five times its primitive volume, and 34127 when the expansion is ten times that volume. Let us add that, in order to find the work corresponding to any particular volume and effective pressure, it is sufficient to form the product of those data by the number in the Table answering to the same expansion. For instance, if we want to know the amount of work done by $0^{cm}\cdot400$ of steam at a pressure of 5 atmospheres and an expansion of five times its volume, we have

$$26964 \times 0^{cm}\cdot400 \times 5 = 53928 \text{ kilogrammètres.}$$

The preceding notions are sufficient to convey a practical knowledge of the conditions that determine the existence of the agent that animates the motors now under consideration.

It was clearly necessary that we should first of all become acquainted with its physical properties, that is to say, the laws that govern its simple formation, and the natural phenomena which it presents, before even any application of it is made. The second point was to ascertain its mechanical power or the conversion of its mere physical pressure into work, characterized by a resistance overcome and a distance travelled.

Having demonstrated this, there can be no difficulty in the way of understanding the description and working of a steam-engine.

The amount of work developed through the expansion of steam may be readily found, with

the assistance of the foregoing detailed rules and tables. In addition to these theoretical considerations, the following practical facts must always be observed:—The area of the grate is regulated by the weight of fuel which is to be burnt upon it in an hour, and by the *rate of combustion* a square foot of grate. The mean rate may be taken for Cornish boilers at 10 lbs. of coal a square foot an hour, for factory boilers 14 lbs., and for marine boilers 20 lbs. Boilers having the fire urged by a blast-pipe or a fan consume from 45 to 125 lbs. The economy of fuel depends very much on the proper adjustment of the rate of combustion a square foot of grate to the draught of the furnace. A certain rate of combustion, which may be found by practical trials, is the best suited to insure thorough combustion in a given furnace; and this fixes the best area of grate; if the grate is made smaller, the combustion becomes imperfect; if larger, too much air enters, and heat is wasted in warming it. It is best, in practice, to make the grate area at first rather too large, and then to contract it by means of fire-bricks, until the smallest area is obtained upon which the required quantity of coal can be burned without incomplete combustion.

When air is admitted above the fuel to burn the coal gas, a smaller area of grate is required to burn a given quantity of fuel an hour than when the whole supply of air has to pass through the grate.

The *length* of a grate should not much exceed 6 ft., in order that the fireman may easily throw coals to the back of it. It may be as much *less* than 6 ft. as the dimensions and figure of the boiler require. The *breadths* of grates range from about 15 in. to 4 ft.; the most convenient breadths for firing being from 18 in. to 2 ft., or thereabouts. The grates of stationary and marine boilers are usually long and narrow; those of locomotive boilers are usually almost square, and sometimes round.

To facilitate the even spreading of the fuel, the surface of an oblong grate is in general made to *slope downwards* from the furnace-mouth to the bridge at the rate of about *one in six*. Its clear height above the floor of the ash-pit should be at least 2½ ft. in front.

A locomotive grate is usually level; and the place of an ash-pit is supplied by a rectangular wrought-iron pan about 10 in. deep, which is open at the front, to catch the air as the engine rushes through it, and can be removed when required.

A grate consists of *fire-bars*, and of *cross bearers* by which they are supported. The fire-bars are made in lengths of from 2 to 3 ft. They are from ⅜ in. to ¾ in. broad on the top, and are often made to diminish to about half that thickness at the lower edge, in order to admit of the free entrance of air and escape of ashes. Their ordinary depth is about 3 in. The breadth of the clear space between two bars is from one-half to two-thirds of the greatest breadth of a bar. At each side of each end of a bar there are snugs or projections, by which the breadth of the bar at its ends is increased so as to be equal to the distance from centre to centre of the bars. When the bars are laid upon the cross bearers with the snugs touching each other, the proper spaces are left between their intermediate parts. Fire-bars are often cast in pairs, so that two bars with the proper space between them form one piece. This saves time in removing and replacing them when the grate requires repairs.

Many contrivances have been devised for supplying fuel to furnaces gradually and equably by mechanism, in order to insure complete combustion. Some of these inventions involve the use of moving grates. The *revolving grate* is circular and horizontal, and turns slowly about its centre. The fuel is dropped upon it by degrees through a fixed opening, and thus every part of it is at all times equally covered. *Another grate* consists of an endless web of very short fire-bars, moving on horizontal rollers, travelling from the furnace-mouth to the bridge, and returning through the ash-pit. The portion of the web which at any time is uppermost is supported on small wheels with which the bars are provided, and which rest on rails. Sometimes the fire-bars, by means of cams, are made to have a short reciprocating motion up and down, and from side to side, in order to keep them clear of clinkers.

The clear height of the *crown* or roof of the furnace above the grate bars is seldom less than about 18 in., and often considerably more. In the fire-boxes of locomotives it is on an average about 4 ft.

The height of 18 in. is suitable where the crown of the furnace is brick arch, as in *detached* furnaces. Where the crown of the furnace, on the other hand, forms part of the heating surface of the boiler, a greater height is desirable in every case in which it can be obtained for the temperature of the boiler plates, being much lower than that of the flame, tends to check the combustion of the inflammable gases which rise from the fuel. As a general principle, *a high furnace is favourable to complete combustion.*

The height of the furnace is limited in practice, sometimes by the necessity for having flues or tubes traversing the water above it, and always by the necessity for having a sufficient depth of water above the crown—that is to say, about 12 or 15 in. in marine boilers, 5 or 6 in. in locomotive boilers, and 10 or 12 in. in land boilers.

According to M. Peclet, the best furnace for burning wood under a steam-boiler consists of a hearth of fire-brick, with a sort of *hopper* or feeding passage in front, of the full width of the hearth, made of cast-iron. The wood, cut into billets whose length is a little less than the width of the hearth, is placed crosswise in the hopper, and descends gradually either by its weight alone, or by its weight aided by the pressure of the feet of the stoker. As it reaches the hearth billet by billet, it takes fire, and is completely consumed. The hearth has a slight slope forwards towards the bottom of the hopper. The whole supply of air for the combustion of the wood passes down through the hopper amongst the unconsumed billets of wood. The ashes are swept away by the draught.

The use of the dead-plate is to insure the combustion of highly bituminous coal. In some of Watt's furnaces it was nearly as long as the grate; but a length of about 20 in. has been found to answer well in some recent practical examples. When the dead-plate forms the bottom of a cast-iron mouthpiece, it is useful to make the roof of that mouthpiece slope downwards towards the furnace at the rate of *one in six*, or thereabouts. This has the effect of directing any current of air

which may enter through the mouthpiece downwards upon the surface of the burning fuel, so as at once to promote rapid combustion of the coal gas, and to prevent that current from striking the crown of the fire-box, which, when that crown is part of the boiler surface, tends both to lower its temperature and to oxidate the plates. In some furnaces the sides and top of the mouthpiece are made thick enough to be traversed by a row of longitudinal holes, each ½ in. in diameter. These holes admit small currents of air, which have some effect in burning the coal gas, but whose principal use is at once to keep the mouthpiece cool and to carry back to the furnace the heat which would otherwise be lost by conduction through the metal of the mouthpiece.

In some furnaces the dead-plate is double, and a current of air is admitted through the passage.

As to contrivances for preventing waste of heat through the fire-door and furnace front, and for admitting air through them to burn the coal gas, and regulating the admission of that air and of the air which enters through the ash-pit, reference is made at p. 438 when treating of marine boilers. To what is stated there, it may be added that doors consisting of several layers of wire gauze have lately been used for these purposes, and, it is said, with good effect; and also, that a heap of dross, slack, or sawdust, where those substances are burned, blocking up the mouthpiece, which is without a door, has been found to answer the same end extremely well in stationary boilers at St. Rollox Chemical Works. The heap so placed intercepts the radiant heat, and admits through its interstices enough of air to carry the sensible part of that heat back into the furnace, and to burn the gases distilled from the fresh fuel. When the fireman considers that the heap is sufficiently coked or charred, he pushes it forward and spreads it uniformly over the grate, and supplies its place by blocking the mouthpiece again with a heap of fresh fuel.

The means of producing a current of air through a furnace, and the principles of the action of those means, and their peculiar effects, are considered in the article on CHIMNEY. Care must be taken not to direct streams of fresh air against the plates or other metal surfaces of the boiler; because if so directed, they produce rapid oxidation.

The only figures for the *shells* of boilers which are safe against bursting by internal pressure, without the aid of stays, are the cylinder and the sphere.

Portions of boiler shells which are flat, or which otherwise deviate from the cylindrical and spherical figures, are strengthened by means of stays. The usual *pitch* or distance apart of the stays of locomotive fire-boxes is about 4½ or 5 in., and of marine and stationary boilers 12 to 18 in. According to Bourne, the staying of existing marine boilers is seldom sufficiently strong; and the iron of the stays ought not to be exposed to a greater working tension than 3000 lbs., on the square inch, in order to provide against their being weakened by corrosion. This amounts to making the *factor of safety* for the working pressure about 20.

If any part of the surface of a boiler cannot be efficiently stayed by rods reaching across to the opposite part, it may be fastened by bolts or rivets to a series of ribs crossing it, care being taken that the ends of those ribs have sufficient support. For example, the flat crown of a locomotive fire-box is hung by bolts from a series of parallel ribs, which cross it at distances of from 4½ to 5 in. from centre to centre, and whose ends are supported on the front and back of the fire-box.

It has been found by experience that a thickness of about ⅜ of an inch is the most favourable to sound riveting and caulking of boiler-plates; and therefore they are seldom made much thicker or much thinner than that thickness. If a cylindrical boiler is required to withstand a very high pressure, the necessary increase of strength must be attained, not by increasing the thickness of the plates, but by diminishing the diameter of the shell. The strongest boilers are those which are entirely composed of tubes and small cylinders, with the water and steam inside.

Fairbairn's experiments have shown that the stay-bolts of locomotive fire-boxes should have their diameters equal to double the thickness of the plates, if these are of iron, so that for ½-inch iron plates the stay-bolts should be ¾ in. in diameter. According to the principles laid down by Bourne, the factor of safety for the stays of marine boilers should be about three times the factor of safety for those of locomotive boilers; hence for plates of ⅜ in. thick or thereabouts, the stays of marine boilers, if round, should be about 1¼ inch in diameter.

The flat ends of cylindrical boilers are made about once and a-half the thickness of the cylindrical barrels, and are tied to each other by longitudinal stays, or to the sides of the boiler by gussets. A pair of tube-plates are tied together in the same manner; and it is safer to rely altogether on stay-rods, to prevent them from being forced asunder, than to leave any part of the tension to be borne by the tubes.

Tubes for the passage of flame and hot gas are made of brass or of iron, and are from 1½ to 2 in. in diameter for locomotives, and from 2 to 4 in. in diameter for marine boilers. They are fixed tight in the holes in the tube-plates, either by driving ferules into their ends, or by riveting up the edges of the ends themselves, so as to make them fit countersunk grooves which surround the holes on the outside of each tube-plate.

The flat ends of cylindrical boilers are very commonly connected with the barrels and flues by means of rings of angle iron; but such rings are liable to split at the angle, and therefore it is considered preferable to make the connection by bending the edges of the endmost plates of the barrel and flues. A flat end to a cylindrical shell, or a flat top to a cylindrical steam-chest, connected by means of an angle-iron ring alone, without stay-bars or gussets, is dangerous at high pressures, even when of small diameter; as the angle-iron ring, although it may last for a time and be apparently safe, is almost certain to split at the angle in the end.

The shells of stationary and locomotive boilers are usually single-rivetted—those of marine boilers usually double-rivetted—that is, the rivets form a zig-zag line at each joint. Horizontal overlapped joints should have the overlapping edges facing upwards on the side next the water, that they may not intercept bubbles of steam on their way upwards. The joints in horizontal flues should be so placed that the overlapping edges shall not oppose the current of gas.

Those parts of boilers which are exposed to more severe or more irregular strains than the rest, or to a more intense heat, should be made of the finest iron, such as Bowling or Lowmoor. This applies

to the sides and crowns of internal furnaces, to tube-plates, to bent plates at the end of cylindrical shells, and so on.

The *sectional area of the flues* of a boiler must not be made too large, lest it should make the boiler too bulky; nor too small, lest it should cause too much resistance to the draught. Experience has shown that a sectional area of from *one-fifth* to *one-seventh* of the area of the grate answers well in practice. When there is a bridge contracting the entrance to the flue, this applies to the area of the passages left by the bridge. In multitubular boilers, the area to be considered is the *joint area of the whole set of tubes*, which, when there are ferules at their ends, is to be measured *within the ferules*.

The course taken by the current of hot gas through the flues and tubes of a boiler is most commonly from below upwards on the whole, even when most of those passages are horizontal. It was first shown by Peclet, and is now generally recognised, that a great advantage in point of thorough convection of heat, and consequently in economy of fuel, is gained by causing the course of the hot gas to be on the whole from *above downwards;* because then the hottest strata of the furnace gas, being uppermost, spread themselves out above the denser and colder strata which are below, and so diffuse themselves more uniformly throughout all the passages than they do when made to ascend from below. This principle was practically applied in Dundonald's boiler, Fig. 868.

The lower horizontal, or nearly horizontal, surfaces of internal flues and tubes, owing to the difficulty with which bubbles of steam escape from them, are found to be much less effective in producing steam than the lateral and upper surfaces. On an average, the effective heating-surface is from $\frac{3}{4}$ to $\frac{5}{6}$ of the total heating-surface.

A cylindrical boiler is usually filled with water to three-fourths of its depth or thereabouts.

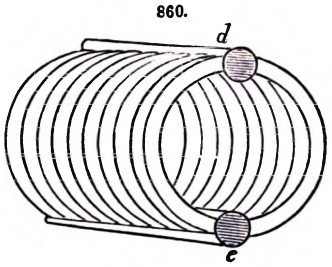
The practice with regard to the absolute capacity of boilers varies very much. According to Robert Armstrong, that capacity ought to be:

*For each cubic foot of water evaporated an hour—*

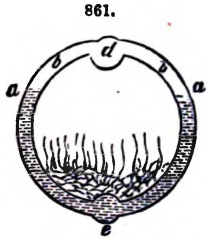
| | |
|---|---|
| Steam-room .. .. .. .. .. | 13½ cubic feet. |
| Water-room .. .. .. .. .. | 13½ „ |
| Total boiler-room .. .. | 27 |

W. H. James' boiler was composed entirely of tubes of small diameter arranged side by side, as in Fig. 860, and inserted into two large pipes *d*, *e*. One of these tubes or rings is shown in section, Fig. 861, and exhibits the space occupied by the water *a a*, the steam room *b b*, the horizontal pipe *d* serving for a steam-pipe, the feed pipe *e* which distributes the water into the rings uniformly. The thickness of the rings was $\frac{3}{16}$ in., of the horizontal pipes *d* and *e* $\frac{3}{4}$ in., and the diameter of the boiler 24 in. The fire was placed on a grate near the bottom, and sometimes directly on the tubes, which thus formed the grating itself. This boiler was enclosed by brick-work, from inside the arched roof of which much heat was economized by reverberation. James patented this boiler in 1825, and he may be considered to be the first inventor who practically understood what was required to constitute an efficient boiler. The comparative merits of the boilers specified in the succeeding tabulated arrangement can, in a great measure, be comprehended from the appended data and registered results.

860.




861.




The boiler invented by Nathaniel Ogle is shown in Figs. 862, 863, 864.

Fig. 862 shows a vertical section of Ogle's boiler, Fig. 863 is a ground plan, and Fig. 864 section of the top.

*a*, *a*, *a*, are tubes or vessels placed over the furnace B in an upright or perpendicular or vertical position. *c*, *c*, are tubes or pipes for connecting the tubes *a*, *a*, *a*, together. *d*, *d*, *d*, are the inner flues which run through the inside of the tubes or vessels *a*, *a*, *a*, and out at the top, and which flues or tubes are also placed in an upright or perpendicular or vertical position, and are for the escape of the heated air or gas arising from the fire, which may be made on the furnace bars *e*, or in any other way that may be found convenient. *f*, *f*, *f*, are flues or spaces which also serve for the escape of the heated air or gas arising from the fire. *g*, *g*, are the sides of the furnace; the front is supposed to be taken away, in order to show the boiler or generator. *h*, the chimney. *i*, *i*, *i*, are bolts for screwing the tubes or pipes *c*, *c*, together. *k*, the feed-pipe for supplying the boiler or generator with water. *l*, the steam-pipe. *m*, *m*, *m*, are tubes or pipes to connect the tubes or pipes *c*, *c*, together. *n* is the ash-pit. The water which is contained between the tubes or vessels *a*, *a*, *a*, may be pumped into the boiler or generator to any height at which it may be found most convenient, and a safety-valve may be attached in the usual way.

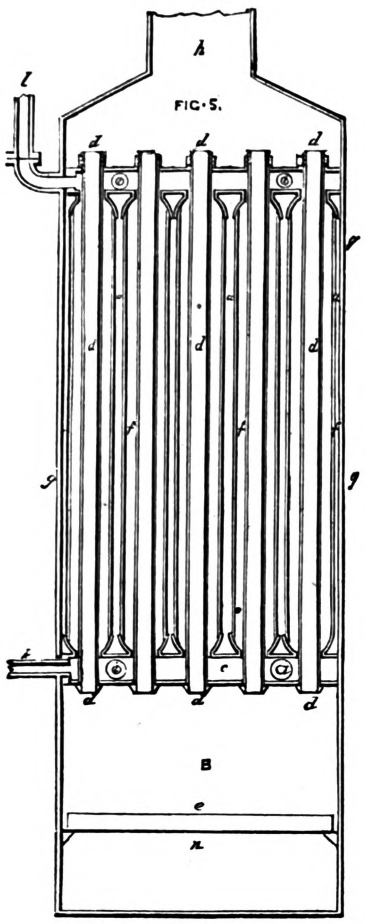
From a series of well-directed experiments, Ogle brought his boiler to a great state of perfection; he received much practical assistance from Thomas Don, the experienced millwright and engineer, who for a considerable time was engaged with Ogle in carrying out steam locomotion on common roads. One of the last arrangements given to Ogle's boiler is shown in Fig. 865: one of the horizontal tubes, detached, is shown in Fig. 866; the dimensions, shown at A, 3 by 3¾ in.; length, 3 ft. 4 in.

This boiler was composed of eleven rows of perpendicular tubes, ten tubes in each row; the internal diameter of the upright tubes was 3 in.

After a series of experiments, Ogle and Don so proportioned the heating-surface to the volume

| Inventors. | Number of Tubes. | Diameter of Tubes. | Length of Tubes. | Superficial Area acted on by Fire. | Cubic Contents of Water and Steam. | Proportion of Area to Contents of galls. Heated by Number of Feet. | Diameter and Number of Cylinders. | Length of Stroke. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| James, boiler in the coach at Epping Forest. | 136 | 1 in. | 2 ft. 3 in. | 125 ft. | 4155 cub. in. 15 galls. | 8·0 | 2 cylinders, 3½ in. area, united area, 19·2. | 12 in. | Coach, driven at great speed, 3 tons, and 28 passengers. |
| **1825.** | | | | | | | | | |
| James, boat boilers at Vauxhall. | 272 | 1¼ in. | 4 ft. | 353 ft. | 19584 cub. in. 70 galls. | 7·0 | 2 cylinders, 5 in. diam., 39·2. | 18 in. | Drove a boat on the Thames 5 miles an hour against tide. |
| James, coach at Vauxhall. | 280 | ⅝ in. | 2 ft. | 107⅛ ft. | 4099 cub. in. 14 galls. | 9·7 | 4 cylinders, 2 in. diam. | 12 in. | Drove coach 12 miles an hour, weight 2 tons, 6 passengers, and a drag. |
| James, 30 H.P., Birmingham, 3 cellular plates. | 57 cells. | 2 in. | 10 ft. | 240 ft. | 21204 cub. in. 76½ galls. | 3·1 | 3 ft. | 6 ft. | Drove 30 H.E. with less fuel and less fire-surface, but was obliged to add more steam room as recipient for low pressure. |
| James, 4 H.P., to drive factory engine at Vauxhall. | 50 | 1 in. | 3 ft. 9 in. | 6975 sq. in. 48⅜ ft. | 1755 cub. in. 6⅛ galls. | 7·7 | 3⅛ in. diam. 9·6 area. | 1 ft. | Drove lathes at Vauxhall, and proved with 2 pumps and by proof bar to 4 H.P., steam 200 lbs. to the inch. |
| James, at Salt's Birmingham driving factory. | 1 cellular plate 7 × 3, and 6 in. deep. | 6 in. deep. 4 in. of water. | 7 ft. long. | 42 ft. | 18144 cub. in. 65 galls. | 0·63 | 1 cylinder, 5 in. diam., 70 lbs. steam. | 12 in. | Drove 16 lathes for brass turner = 4 H.P., 75 to 90 strokes a minute, 2½ cwt. slack a day. |
| Ogle .. .. .. .. .. | 144 within. | 4 in. | 3 ft. 6 in. | 788 ft. | 48816 cub. in. 176 galls. | 4·4 | 2 cylinders, 11½ in. diam. | 18 in. | Weighed from 4 to 5 tons, carried 14 passengers at about 10 to 12 miles an hour. |
| **1830.** | | | | | | | | | |
| Ogle, large coach .. .. | 112 | 4 in. out. 1⅛ in. in. | 20; 3 ft. 6 in. remainder 3 ft. | 71092 sq. in. 486 ft. | 47070 cub. in. 170 galls. | 2·8 | 2 cylinders, 11½ in. diam. | 18 in. | Drove coach weighing 6 tons at 16 miles an hour, wheels 5 ft. diam., steam 200 lbs. |
| Ogle, light coach .. .. | 80 | 4 in. out. 1⅛ in. inside. | 16; 3 ft. 6 in. remainder 3 ft. | 48800 sq. in. 338 ft. | 33738 cub. in. 122 galls. | 2·7 | 2 cylinders, 7 in. diam. | 18 in. | Weight of coach, 3½ tons, ran 18 miles an hour, 14 passengers. |
| Ogle, new boiler for the large coach. | 133 | 3½ in. 5 in. the horizontal. | { 110; 2 ft. 6 in. 20; 3 ft. 4 in. 3; 4 ft. 2 in. } | 46306 sq. in. 320 ft. | 50534 cub. in. 182½ galls. | 1·2 | 11½ in. diam. | 18 in. | |
| Hancock, steam coach .. | 12 plates. 20 tubes. | 2 ft. 6 in. × 3 ft. | .. .. | 27216 sq. in. 188 ft. 315 ft. | 19440 cub. in. 70 galls. 116 galls. | 2·7 | 2 cylinders, 8 in. diam. | 16 in. | Drove coach, 3½ tons, with 14 passengers and 3 engineers, average 8 miles an hour. |
| **1827.** | | | | | | | | | |
| Macerone, steam coach .. | 81 | 4 in. diam. 3⅛ in. diam. | 54 in. 36 in. | 41901 sq. in. 291 ft. | 33290 cub. in. 127 galls. | 2·3 | .. .. .. .. | .. | Coach at Paris ran very well. |
| Busk, 10-H.P. boiler .. | 28 | 3½ in. | 8 ft. | 233 ft. | 25536 cub. in. 92 galls. | 2·4 | .. .. .. .. | .. | Evaporated 200 galls. an hour. |
| Perkins, boilers at Russell's. | 98 | 2·4 in. inner. 3 in. outer. | 18 in. | 131 ft. | 72 galls. | 1·8 | .. .. .. .. | .. | 10 H.P. |
| **1822.** | | | | | | | | | |
| Stephenson, railway coaches, 14 H.P. | 108 | 1¼ in. 2 in. | .. .. | 253 ft. | 59371 cub. in. 214⅛ galls. | 1·1 | 2 cylinders, 11 in. diam., 50 lbs. | 17 in. | Evaporates nearly a cubic foot or 6·2 galls. a minute, 372 galls. an hour. |
| **1815.** | | | | | | | | | |
| Nash, boiler put up at Wormley, near Bristol. | .. .. .. | .. .. .. | .. .. | 16777 sq. in. 119 ft. | 38181 cub. in. 138 galls. | 0·8 | .. .. .. .. | .. | 8 H.P., burnt 4 cwt. of coals in 12 hours, driving 2-pr. stones, or 7 lbs. each H.P. an hour. |
| Long, American boiler, see 'Mechanic's Magazine,' vol. xx. | 2 boilers, 9 ft. 8 in. 20 in. diam. 20 tubes in each | .. .. .. | .. .. | 35952 sq. in. 241 ft. | 58488 cub. in. 211 galls. | 0·8 | .. .. .. .. | .. | Evaporated 200 galls. an hour, 90 lbs. an inch, 2 bushels anthracite coal. |
| Hancock, boat 'Minerva,' 1837. | 12 plates of chambers | 3 ft. 6 in. × 4 ft. | .. .. | 49392 sq. in. 343 ft. | 72576 cub. in. 262 galls. | 1·3 | 2 cylinders, 14 in. | 3 ft. | Drives the 'Minerva,' 1 condenser, 40 to 45 strokes a minute. |
| Marshall, 2 boilers .. .. | Flue boiler, 1 flue returning. Boiler, 3 ft. 2 in. diam., 16 ft. long. Fireplace, 2 ft. 1 in. diam., 4 ft. long. Flue, 20 ft. long, 1½ ft. diam. | | .. .. | 15126 sq. in. 105 ft. | 110808 cub. in. 400 galls. | 0·26 | 14 in. | 3 ft. | Hardly drove the boat with these two boilers; oscillating steam-engine, 35 strokes. |

462

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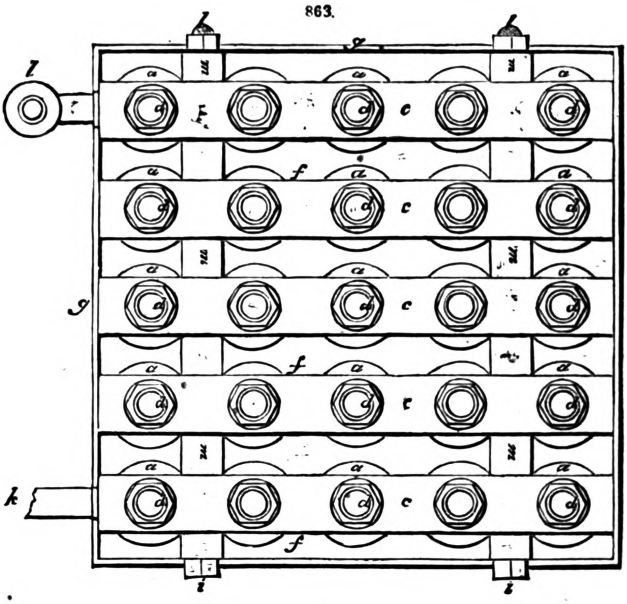

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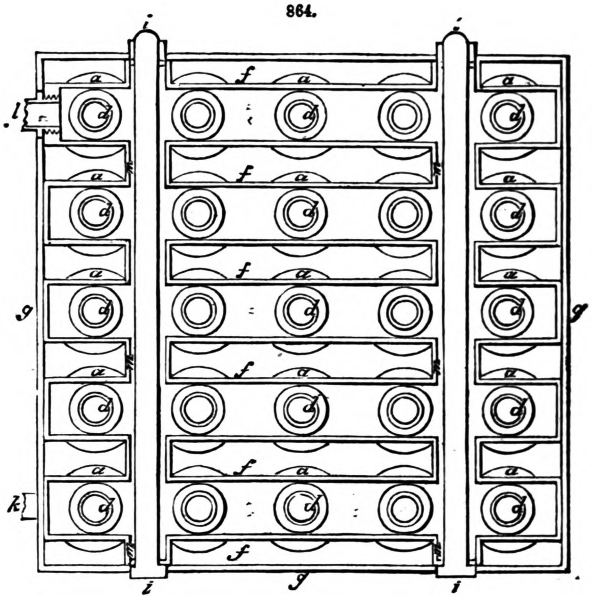

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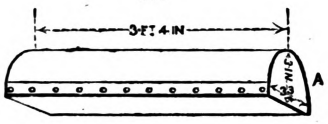
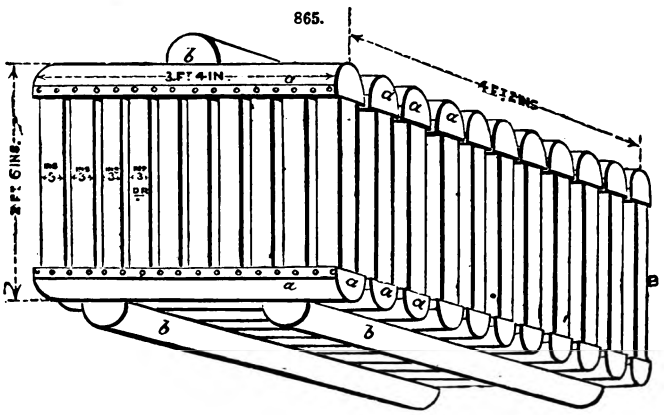



865.



of water to which it communicated a maximum calorific value, that they dispensed with the inner flues, and ultimately produced a boiler of the type shown in Fig. 865. Ogle inserted a steam-pipe at *b*; this pipe was pierced with holes like that shown in the Thomson boiler, Fig. 835. The holes in Ogle's superheating and drying tube were not equidistant; they stood farther apart, near the exit at *b*. Ogle possessed great mechanical skill, as well as extensive general information; he was highly educated in both college and school. In early life he was an officer in the Royal Navy; his attainments in other departments of science and art were considerable, and no man possessed a heart with a greater amount of the milk of human kindness than Nathaniel Ogle. The writer knew him well; peace be to his ashes.

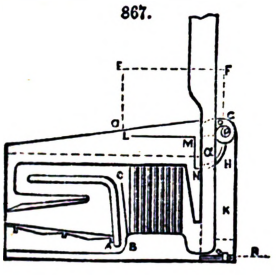
The boiler shown in Fig. 865 had

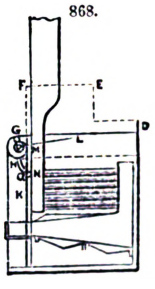
| | | sq. in. |
|---|---|---|
| 110 upright tubes; surface of each was 351 sq. in.; in all .. .. .. | | 38,610 |
| 22 horizontal tubes *a*, *a*, *a*; surface each 320 sq. in.; in all .. .. | | 6,400 |
| 3 horizontal tubes to join the rows of tubes at top and bottom, for water-supply and to take off the steam; the surface, in all .. | | 1,296 |
| Or 320 sup. ft. or heating-surface contained in a space of 34½ cub. ft. | | 46,306 |
| | | cub. in. |
| Solid contents { Upright tubes, 288 cub. in.; in all .. .. .. .. | | 31,680 |
| Solid contents { Horizontal tubes .. .. .. .. .. .. .. .. | | 18,424 |
| Or 180 gallons. | | 50,104 |

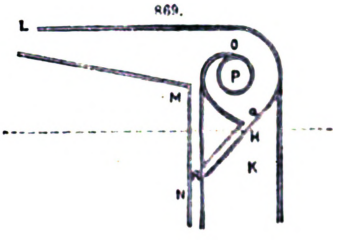
The Dundonald boiler is shown in Figs. 867 to 871; this arrangement is original and very complete.

Fig. 867 is a general view of the boiler invented by Thomas Cochrane, commonly called Earl Dundonald. A is an aperture at the back of the ash-pit to admit heated air through a duct or channel B, C, to unite with the candent gaseous products of combustion at C, and complete the decomposition of fuliginous matter. From this boiler Dundonald cuts off the steam-chest D, E, F, G, reducing the altitude of the boiler to D, G, and in lieu of the steam-chest he adds a reservoir H, K, of sufficient capacity, using the device L, M, being a plate of iron or other substance, whereof the part M may either be immersed in the water, or a pipe or channel M, L, may be added, whereby the spray or water hurried up by the steam may descend, so that the steam which shall enter the centrifugal separator O, P, may be comparatively dry; but should any spray remain enveloped by the steam, the same will adhere to and fall down from the separator through the tube or channel Q, which performs the same office as M, N. It is obvious that these channels, being immersed at their lower extremities, do not permit the flow of steam in a direction contrary to the issue of the separated water.

Fig. 868 exhibits a common tubular boiler, from which the lofty appendage of a steam-chest may be removed and the steam reservoir substituted. H, K, represents that reservoir, and D, E, F, G, the steam-chest cut off, which important improvement Dundonald renders practicable by devices that retain the spray or water termed *priming*. L, M, is a guard to ward off the effect of violent ebullition, and at M, N, is an opening or channel (the lower part whereof terminates under water to prevent a counter-current of steam), through which opening or channel the greater part of the *priming* descends, leaving the steam comparatively dry to enter the centrifugal separator O, P.



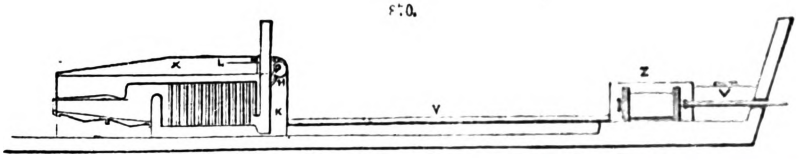



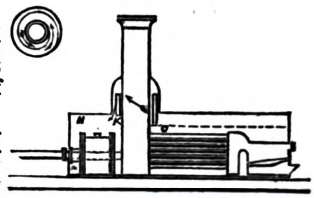

Fig. 869 is an enlarged view of that separator, on the sides of which the remaining spray impinges by its rectilinear impulse, and adheres until it descends through a submerged pipe or channel Q, and returns into the boiler. The dry steam enters the reservoir H, K, at the ends of the separator O, P, by the openings P, the rest O being closed. But in constructing boilers it is proposed wholly or partly to envelop the funnel in the reservoir, and so render the steam still more dry by imparting thereto the heat which the products of combustion may then and there be

able to impart. Condensed steam may be drawn off from the reservoir H, K, and returned to the boiler by a small transfer-pump R, or by a connection with the feed-pump, or it may be blown out through a pipe by the steam pressure.

Fig. 870 shows a means of communicating power to propelling apparatus without long shafts or the ordinary gear. *x* is a steam generator; *y* is a steam-pipe enclosed in a case composed of the least-conducting material to prevent loss of heat; and *z* is a steam reservoir, placed as near the extremity of the vessel as may be convenient; thus a short propeller-shaft from an engine contiguous thereto will suffice. Contiguous to the reservoir *z*, and reaching to the stern-frame, Dundonald placed a water or an air and water tight tank, through which the propeller-shaft passes, whereby the bearings were kept cool, and leakage from the stuffing-boxes prevented.

Fig. 871 is a boat boiler, which, as regards its steam-generating arrangements, may be on the usual locomotive plan. Dundonald's improvements consisted in placing around the funnel, or where most convenient, a steam-separator to ward off the effect of violent ebullition or external agitation, and draw off the spray or *priming* arising therefrom by the pipe or channel M, N, or Q, leaving the steam comparatively dry to pass into the lower reservoir H, K.

871.



Dundonald justly claims the constructing of boilers with steam reservoirs below the level of the water in lieu of and dispensing with steam-chests above; and also the means of retaining the heat and drying the steam in a reservoir by the presence of a portion of fire-surface, or by the passage of the flue or chimney therein.

His invention also prevents the overflow of water, termed *priming*, into a steam reservoir by protecting plates or channels, having grooves or ducts, whose lower extremity is immersed in water within the boiler, or terminates in the steam reservoir, and so leaves a free issue for the *priming* which separates from the steam. Dundonald also rightly claims a spiral or other centrifugal separator, which for the purpose might be square or other shape, and still perform the office of separator on the principle thereof; and the introduction of a submerged opening, groove, pipe, duct, or channel, whereby the spray or water so separated may descend or pass off unopposed by a counter-current of steam.

About the year 1846 James Montgomery introduced the boiler arrangements shown in Figs. 872, 873.

872.

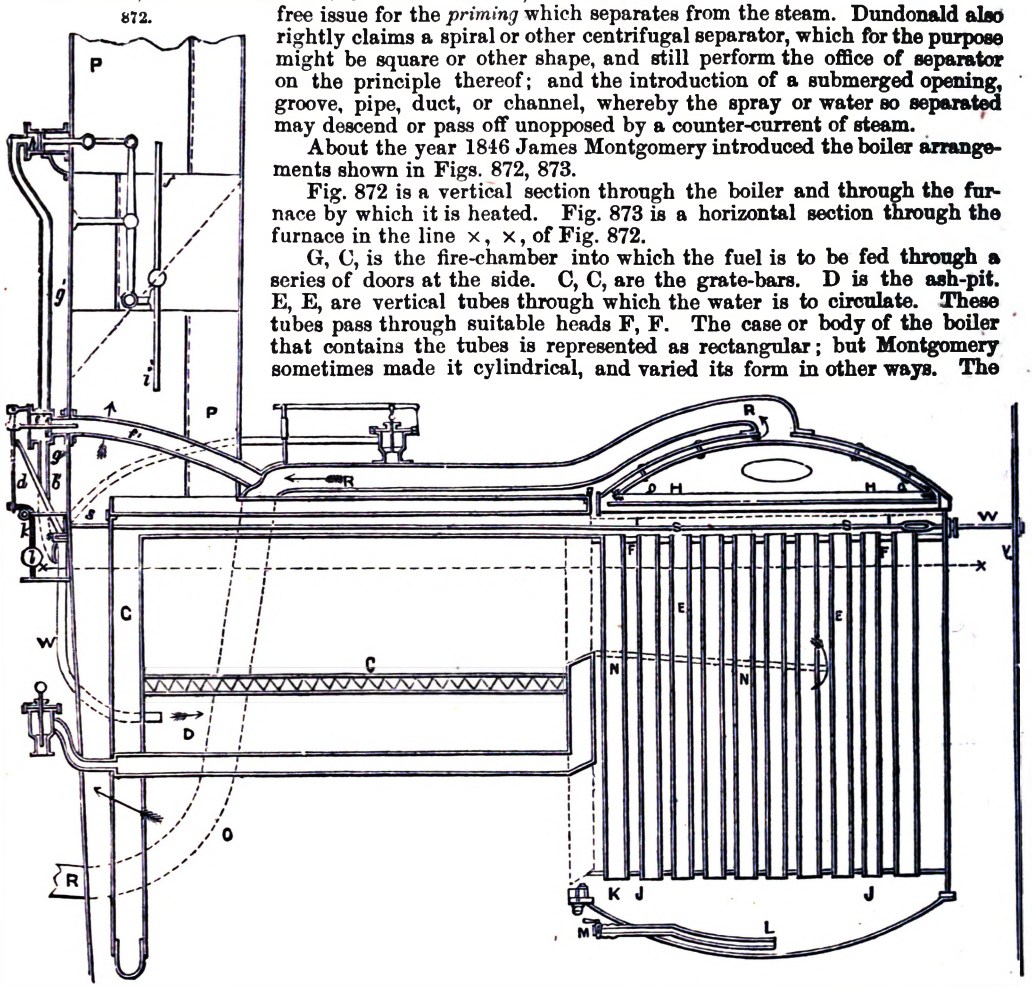
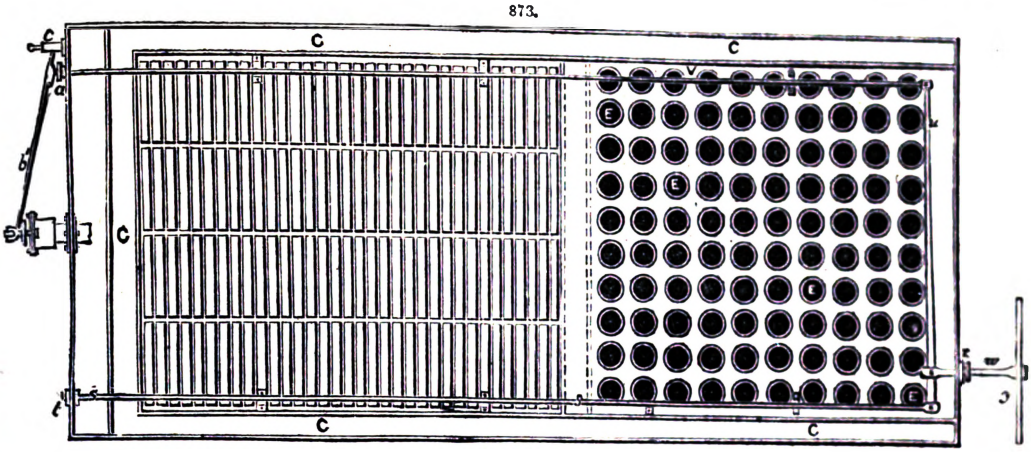



Fig. 872 is a vertical section through the boiler and through the furnace by which it is heated. Fig. 873 is a horizontal section through the furnace in the line ×, ×, of Fig. 872.

G, C, is the fire-chamber into which the fuel is to be fed through a series of doors at the side. C, C, are the grate-bars. D is the ash-pit. E, E, are vertical tubes through which the water is to circulate. These tubes pass through suitable heads F, F. The case or body of the boiler that contains the tubes is represented as rectangular; but Montgomery sometimes made it cylindrical, and varied its form in other ways. The fire-chamber is surrounded by a water-space G, G, which is continued on the sides of the containing case of the vertical tubes. H, H, is the steam-chamber; I, I, the water-line; J, J, that portion of the boiler that is below the lower tube-head; and K, K, the bottom of the boiler. This bottom is made convex outwards, and may be either spherical or conical; and as the heat from the fire does not act on this bottom, the water contained between it and the lower tube-head

will be in a state of comparative quiescence, in consequence of which the sedimentary matter, from which incrustations are ordinarily formed on the bottoms and other parts of boilers, will settle down in a loose unaggregated state. By means of a tube L, and a cock M, or by the aid of an ordinary valve, the accumulated sediment may at any time be blown off without occasioning any considerable waste of water.

873.




The flame or heat from the fire-chamber is directed, first, against the upper ends of the vertical tubes, and then upon their lower ends; and to effect this a partition or diaphragm N, N, was placed so as to divide the larger portion of the chamber containing the tubes into two parts, an upper and lower chamber. This will direct the draught, as indicated by the arrows, first into the space above the diaphragm, around which it will pass to the chamber below the diaphragm, thence into the flue-space O, O, below the ash-pit, and thence to the chimney P The introduction of this diaphragm-plate is an important feature, and first introduced by Montgomery.

Q, Q, Fig. 872, is a shield, consisting of a plate of metal placed below the boiler-head at such distance therefrom as to allow of a steam passage between the two; its diameter is somewhat less than that of the boiler-head, so as to allow the steam from the steam-chamber to pass into it whilst it completely covers the upper ends of the vertical tubes. By this arrangement of the shield the steam is drawn equally from all parts of the circumference of the boiler; the foaming of the water when the pressure is taken off by the admittance of steam into the cylinder will also be in great measure prevented. R, R, is the steam-pipe leading from the middle of the boiler-head to the engine.

Montgomery adds:—"The producing of a free and continuous circulation of the water in a boiler has been frequently attempted, but has not been, as I am well assured, hitherto attained; but by my plan of arranging the respective parts of the boiler in such way as that its bottom shall not be subjected to the direct action of heat, and of introducing it laterally among the vertical tubes at their upper ends, I not only secure the ready depositing of the sediment as stated, but effect a rapid and decided circulation, which prevents all incrustation on the interior of the tubes and at the bottom of the boiler, and also augments the quantity of steam generated. I have represented the diaphragm as situated at about one-third of the height of the boiler from its top, but it may be placed near its middle, or lower down if preferred, the fire-chamber also being depressed to accord therewith."

The fire is to be ignited at the part nearest to the boiler, and successively through the doors more and more distant from it, the object of which is always to keep a clear fire towards the boiler, the fireman moving the fuel which has ceased to give out smoke gradually forward, and giving the new supply at a distant door, so as to cause the smoke to pass over a clear fire, by which means it will be completely burnt, the unavoidable leaking in of atmospheric air being sufficient to produce that result; an additional supply may, however, be given should it be found necessary. W, W, Fig. 872, is a waste-steam pipe leading from the ordinary safety-valve into the ash-pit D. This pipe will conduct the steam that escapes through the valve, whether in small or large quantities, into said ash-pit; and when the quantity is large from the effect of too great pressure, the steam will have the effect of damping the fire, and thus of regulating the pressure.

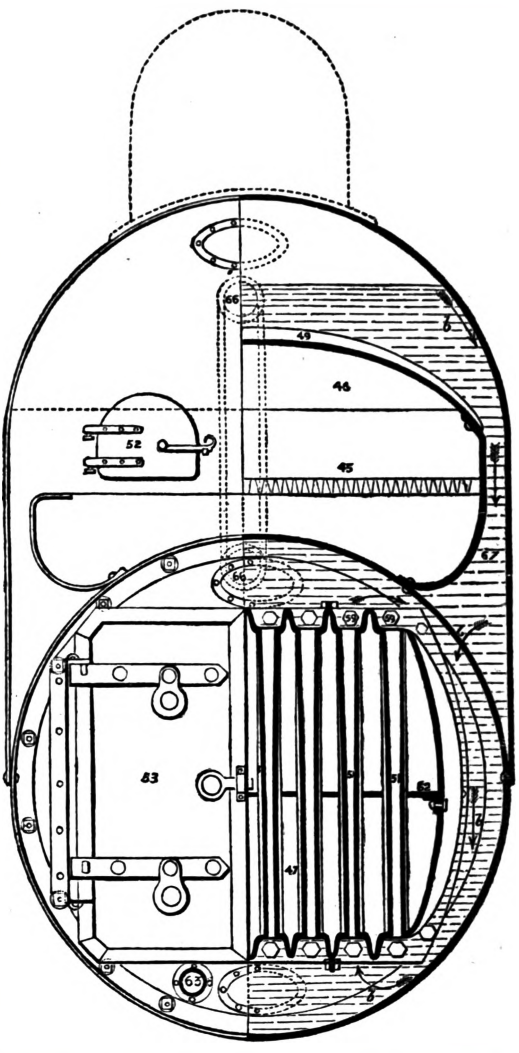
Montgomery also introduced a peculiar method of applying expanding-rods to boilers, for the purpose of preventing explosions by damping the fire before the point of danger was reached.

One form of this arrangement is shown in Fig. 873. $s, s$, is a rod which is made fast to the front furnace-plate, as at $t$. It passes through suitable stays to prevent its bending, is jointed at its rear end to a rod $u$, and this at its opposite end is jointed to a rod $v, v$, that passes to the front of the boiler; $w$ is a rod that passes from the rod $w$, through a stuffing box $x$, and is made fast to an immovable bulkhead at $y$; the rod $w$ consequently remains stationary; the expansion of the boiler and rod by heat will therefore have the effect of causing the boiler to slide back on the rod $w$ and will cause the rod $w$ to force the rod $v, v$, forward. The rod $v, v$, passes through a stuffing-box at $a^1$ on the front of the boiler, and its end bears against a rod $b^1$, which is attached by a joint-pin to a short arm or stud $c^1$.

In the vertical section, Fig. 872, the lever $b^1$ is seen as acting against a lever which operates on a valve $e^1$ that is connected to the steam-pipe R by a smaller pipe $f^1$. When the expansion-rods

force out the valve $e^1$, steam will pass up the tube $g^1$, and force in a piston at $h^1$, and will close the damper $i^1$ by an arrangement of levers, the action of which will be readily understood on inspection. To cause the lever $d^1$ to return with certainty to its place when the expansion-bars contract, a weight $j^1$ is applied to a cord that passes over a pulley $k^1$. The front of the furnace, it is to be observed, is to be so stayed that the whole expansion of it and of the boiler shall be towards the back. Montgomery says, "Instead of carrying the steam from the ordinary safety-valve through the waste-steam pipe W, W, as before mentioned, I sometimes adopt the arrangement of admitting a portion thereof by the action of the expansion-rods. In this case, in addition to the ascending-tube $g^1$, $g^1$, that gives a passage to the steam that is to close the damper $i^1$, I allow a tube $g^{11}$ to descend from the chamber of the valve $e^1$ and to enter the ash-pit; the portion of steam that descends through this tube will co-operate with that which ascends through the tube $g^1$ in damping the fire. The expansion-bars are to be made of any suitable composition, and these, when the boiler is of iron, are to be enclosed in tubes of iron, the expansion of which will be the same with that of the boiler; when the boiler is of copper, the enclosing-tubes must be of that metal. By the enclosing-tubes the expansion-bars are kept from the contact of moisture, and all galvanic action is thereby prevented. The operation of the expansion-rods, when arranged in the manner described, will be such as to ensure the operating of the whole amount of their expansion upon the apparatus by which the damping of the fire is to be effected."

874.




As an inventor, Montgomery has but few equals. We therefore give another form of boiler invented by him about 1859. This boiler is shown in Figs. 874, 875, 876, 877. In part a front elevation, Fig. 874, and in part a vertical transverse section, Fig. 874. The parts shown in these four figures are referred to by numbers instead of by letters.

Fig. 875 is a vertical longitudinal section; Fig. 876 is a transverse section of the upper part of the boiler, exhibiting a modification in the form of the crown-plate; Fig. 877 is a longitudinal interior view of a segment of the cylindrical portion of the boiler, showing the form of passages communicating between the upper and lower portions. 45 represents the furnace, and 46 and 47 flues through which the products of combustion pass to the stack 48; 49 is a corrugated plate of metal, forming the crown of the furnace and the floor of the upper water-space; 50 is a bridge, which serves to deflect the products of combustion upward, and receive the heat therefrom, which is imparted to the body of the water which it contains; 51 are corrugated metallic plates, forming a series of tubes of oblong, elliptical, circular, or other section, between which the products of combustion pass, and through which water circulates or flows upward by the effect of heat, to facilitate which the said tubes are formed of increasing diameter towards their upper ends. The plates are made of greater thickness at their lower parts to preserve them longer from the destructive effect of the deposit of ashes between them. 52 are the fire-doors, and 53, doors giving access to the flues: 54 is a damper which, when open, affords direct communication between the furnace and stack to facilitate kindling the fire. The plates by which the corrugated tubes are sustained and connected at their ends may be either cast or wrought metal. In the former case the ends of the tubes are first upset so as to form flanges, which may be separated and turned to different angles. The tubes are then placed in position in a suitable mould, and molten metal run upon their ends so as to cement the whole firmly together, or form means of connecting them as may be desired. In order to fix the tubes in wrought metal plates, apertures of the requisite size and shape are first formed in the said plates and the tubes inserted therein; the ends of the tubes are then somewhat expanded, and thimbles (56) inserted, which form internal supports, and enable the ends of the tubes to be upset or caulked so as to produce secure steam-tight joints between them and the connecting-plates (58). If preferred, the thimble may be replaced by a simple stay introduced between the opposite salient portions of the plates near their edges. The whole nest of corrugated plates forming the interior water-spaces is held in position by screw bolts (59). which admit of the removal of the whole nest bodily for inspection, cleansing, or

repairs, and the connecting-plate may, if desired, be constructed in sections connected in like manner so as to facilitate the same end. The corrugations in the metallic plates are advantageous in giving strength and rigidity to the structure, and affording an increased extent of heating-surface; and, when placed at right angles to the line of draught, present surfaces against which the products of combustion impinge with some force, and thus temporarily arrest their progress, and cause them to part with more of their contained heat. By means of this arrangement a large portion of the heat produced passes immediately into the upper part of the water through the

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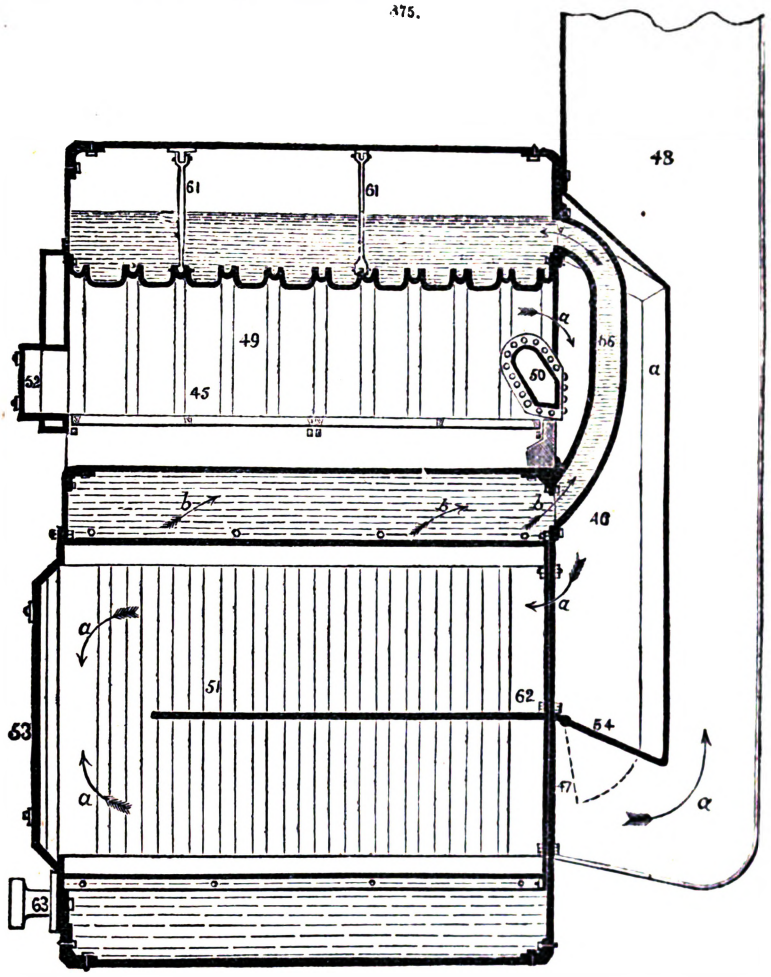


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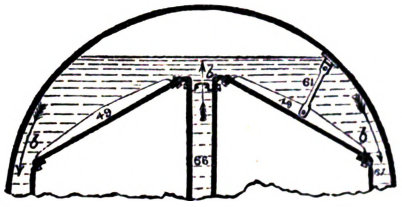


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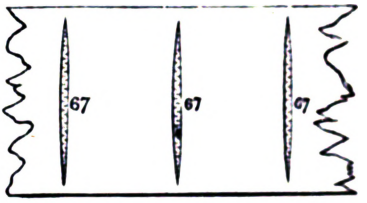


medium of the plate (49), and thus effects the generation of steam, the heat evolved by contact with the plates or tubes (51) serving to raise the temperature of the water contained between them, and to generate an additional amount of steam. When employed for the formation of furnace crowns and plates as (49), the corrugations are preferred to run transversely of the arch or at right angles to its axis, in order to form opposing curves to add to the strength and rigidity of the structure, which end is further accomplished by forming the corrugations of greater depth towards the centre or crown of the plate than at or near its sustained edges or ends, as shown in Figs. 874 and 876. The crown-plate (49) exhibited in Fig. 875 presents in its longitudinal section alternate corrugations of different sizes surmounted by vertical ribs or laminæ (60), which is believed to constitute an original form of plate, possessing greater strength in proportion to the weight of metal than any other known; the ribs (60) also afford facility for the attachment of stays or

braces (61). In high-pressure boilers the corrugations in the plates (51) forming the internal water-tubes will also be rolled of increasing depth toward the centre to give them additional strength. For low-pressure boilers the plates (51) are formed with corrugations running horizontally as well as vertically, the effect of which is to avoid any injury by contraction and expansion from changes of temperature, and also to afford increased heating-surface. In this case the tubes are made circular in the general form of their transverse section.

The operation is as follows:—The products of combustion pass from the furnace (45) over the bridge (50), down the flue (46) to THE DIAPHRAGM-PLATE (62), by which they are deflected horizontally between the corrugated tubes (51) to the end of the said plate (62), where they descend and are carried horizontally in the opposite direction between the lower ends of the tubes (51), and having thus been made to part with a large proportion of their heat, pass upward through the side flues (47) to the stack (48), their course throughout being indicated by arrows *a*. By this means the plates composing the water-tubes are preserved from unequal vertical expansion in their front and rear portions respectively, and the corrugated form of the said plates prevents any injurious results from the greater horizontal expansion of the upper than that of the lower portion. Feed-water (see arrows *b*) is introduced into the lower portion of the boiler through the port (63), and in accordance with the laws of rarefaction by heat a constant circulation is produced, the hottest portion of the water at all times passing to the upper region of the boiler immediately above the furnace, at which point the most intense heat is imparted from the furnace so as to produce there the chief generation of steam, which rises freely in the steam-space without producing any serious ebullition or disturbance of water to cause foaming. In the lower region of the boiler a constant circulation of water occurs up the tubes (51) and down the external water-ways (65), any steam generated by contact with the upper ends of the tubes rising, together with the water with which it is mingled, through the passage (66), and "solid" water descending through the external passages (67) to take its place: it will thus be seen that the present arrangement causes the steam as fast as formed to rise with the water instead of through it, which results in the prevention of foaming and in keeping the water in close contact with the heating-surfaces. The passages (67) communicate with the lower region of the boiler by long narrow ports ($67^1$) running transversely of the boiler, as shown in Fig. 877, which produce no weakening effect, because their combined diameter longitudinally of the boiler is not greater than that of the rivet-holes necessary for connecting the plates. In Fig. 875 the damper (54) is shown located at the bottom of the descending-flue (46), in order that when it is opened any accumulation of ashes may be discharged into the box beneath, from whence it is readily removable; the action of this damper also facilitates the kindling of the fire.

In a paper, by Charles Wye Williams, printed in the 'Trans. of Inst. N. A.,' on the "Construction of Marine Steam-Boilers," Williams says that it is highly desirable to raise a preliminary question, namely, how to realize the greatest calorific effect from the coal by generating the largest amount of heat; and it is only when this is effected, that we come, practically, to the application and utilization of that heat in the boiler, and thus to generating the largest quantity of steam. In speaking of the power by which the engine is made available, we rightly refer to the steam itself. So, when we speak of the amount of power exercised, we refer, practically, to the quantity of steam generated. We may here, then, discard the term *pressure*, so much commented on, because this, when rightly understood, represents but the mere *quantity* confined within the volume of the boiler. On what, then, does this quantity depend? not, certainly, on the mere weight of coal consumed, since any weight may be so misapplied or wasted under an inefficient boiler as to have little effect on the quantity of steam generated. In the generation of heat, the only ingredients are the fuel and the air. Their successful combination belongs to the proportions and appendages of the furnace, wholly apart from the *boiler* placed over it, the result depending solely on the perfection with which that combination is effected. Now, that combination, says Williams, is a purely chemical process, and is determined by the union of due equivalents of the air and fuel. The perfection of this process, however, be it ever so complete, has no fixed relation to the amount of steam generated. To speak, then, in the fashion of the day, of the evaporative value of any description of *coal*, is at once incorrect, delusive, and unmeaning. Strictly speaking, there is no such thing as an *evaporative value* in coal, although we can well understand its heat-generating or calorific value. The generation of heat is a wholly different thing from its application. The importance of this distinction has yet to be appreciated by practical engineers. As the generation of heat is the peculiar province of the *furnace*, or alembic, in which the combustible fuel and the atmospheric oxygen are to be combined, so the generation of steam is the province of the *boiler*, and to this latter belongs the degree of perfection with which that heat will be transmitted to the water, and steam thus produced.

We have, then, two distinct processes or operations to consider: first, the generation of the heat; and secondly, its application, involving the heat-transferring property of the boiler-plates as the direct cause of the generation of steam. To the confusion which has hitherto prevailed in reference to these distinct processes may be attributed the absence of attention to the proportions, conditions, and separate functions of the furnace and the boiler. The consequence of this confusion is, that a wrong direction continues to be given to the inquiries of even the most ingenious and practical men. While we have been endeavouring to ascertain the relative calorific (erroneously called the evaporative) values of different kinds of coal, we should have been considering the relative heat-transmitting properties of the different kinds of boilers. Of this we have a notable instance in the late commission issued under the direction of the Admiralty to inquire into the kind of coal best suited for steam-vessels of war, but in which no reference whatever was made to the peculiarities and imperfections of the boiler employed, and hence the unsatisfactory character of the results, as will hereafter be shown. On this head we have also a report from the late H. De la Beche and Lyon Playfair on the so-called "evaporative power and value of the North of England and South Wales coal." This report assigns to the latter an

evaporative value which is purely theoretical, and altogether erroneous and misleading. In it we detect the grave error of confounding calorific with *evaporative* power, which are there assumed to be identical.

In considering the calorific value of any description of coal, we cannot omit estimating that waste of its constituents which goes to the production of smoke, and the deposit of soot, with its non-conducting property, but which forms no part in a theoretic estimate of its calorific properties. On this point R. Murray has offered some remarks which here demand attention. "However desirable it may be," observes Murray, "in other respects, to 'burn smoke,' by admitting air into the furnace above the bars, this is not always found to be an *economical* process." It is to be regretted that he has offered no evidence in justification of this statement, which, says Williams, I hold to be the very reverse of fact. I can at any time show a boiler in daily work, in which, not only the full calorific value of each description of coal may be ascertained, but in which the economy of combustion with, and without, smoke, is indicated with the greatest certainty. Again, Murray in his paper observes, "the burning of smoke, as it is called, by artificial methods, has not proved very successful in economizing fuel; but that, by proper firing, and by admitting a little air through the doors, black smoke may be prevented from being formed, and more economy would in that way be realized than by using artificial means for burning the smoke." In making these assertions, Murray should have supplied some information as to what he means by the term "artificial"; what it is that he characterizes as "proper firing"; and what is meant by "a little air." Murray, observed Williams, must have been looking at some of the scores of patents, ingeniously varied and elaborated as mere commercial speculations, for effecting, by costly apparatus, the "burning of smoke"; and which may truly be called "artificial," including the most absurd of all, the heating of the air. But if he will refer to the Newcastle experiments he will find, not only that smoke may be prevented, but that a considerable economy may at the same time be uniformly realized. As to the term artificial, if that be applied to the method of introducing atmospheric air, in divided streams, into the furnace, a system which—in continuation Williams goes on to say—I have employed for many years with very great advantage, I can only say that Murray may with equal propriety characterize as artificial the method of allowing water to issue through the perforations in the rose of the common watering-pot, instead of its passing in an undivided stream, as when the rose is removed. This action of the rose is identical with the mode recommended for bringing the air, in divided portions, to the gas in the furnace, for the purpose of a more rapid intermixture. As to admitting a little air, it would appear that the author alludes to the common practice among stokers of opening the doors to a small extent. It ought to be remembered, however—what every chemical authority states—that the 10,000 cub. ft. of gas generated from a ton of Newcastle coal, absolutely require for their combustion no less than 100,000 cub. ft. of atmospheric air, and practically, as Daniel observed, require fully double that quantity for the ordinary working of a furnace; and this independently of the 200,000 cub. ft. required for the coke or fixed portion of the same ton weight, and which must pass up from the ash-pit. The following proof of inattention to these large quantities may here be mentioned. In a large steamer with great power, a difficulty was experienced in raising the required quantity of steam, and the continued discharge of the densest smoke (where the engineer had undertaken that there should be *none*) caused great annoyance. The remedy adopted was the passing of *one of the* 2½*-in. tubes* through the smoke-box into the stoke-room, and thus allowing the air to pass through it to the gases before entering the tubes! It need only be observed that it had no more effect than if the nozzle of a common hand-bellows had been applied. To speak, then, of allowing a little air to enter by the doors, seems likely to mislead, where such large quantities of air are chemically essential to the process. Williams further asks, Where else, then, above the fuel, that is, in the chamber of the furnace (as in the retorts in the gas-works), can the combustible gas be met with, or where else can this enormous quantity of air be required to effect the necessary union and combustion, without which the full calorific and economic value of the coal cannot be realized?

In great operations like these, there can be no advantage in neglecting or counteracting the demands of nature, or in checking the operation of nature's laws. All admit that gas is generated from coal, on its being heated; that atmospheric air is essential for the combustion of that gas, and that the two must be intermixed for chemical combustion; yet we violently interfere by allowing neither time nor space for these operations, and in most cases absolutely prohibit the introduction of any air at all, by the interposition of closely-fitting doors! What, then, can we expect but imperfection in the process and the most unsatisfactory results! Is it not, in truth, worse than stupidity or folly to neglect the conditions and means by which alone the constituents of the fuel can be enabled to unite, and combustion be effected, or the full calorific value of the coal be realized?

On one occasion which came within my own notice, and where the door-plate box had been fitted with the proper number of orifices, the engineer observed that my own plan had been adopted. In reply, I asked if he had ascertained that any, even the smallest quantity of air had passed in through the 300 ½-in. orifices. The orifices were duly provided, and it was assumed, as a matter of course, that the air would enter through them. On investigation, however, it was found that no air whatever had passed inwards through those holes. The furnace-bars being 7 ft. long, and the chamber so shallow that the fuel actually touched the crown of the furnace, the back ends of the bars were necessarily uncovered, and the volume of air which there entered was so great that the space over the bridge was insufficient for its passage, and consequently, instead of any air passing inwards through the perforated door-plate, much of the air and products of combustion (the flame included) actually went the wrong way, returning, and forcing the flame against the door-plate, and outwards through the holes, so as to destroy the door, producing what is known by the term "back-draught."

Williams, in continuing this argument, remarks that Murray has stated that not only is economy not effected by admitting air into the furnace above the bars, but "considerable caution

is necessary for the due regulation of the quantity of air thus admitted through the fire-doors." To these statements, says Williams, I can in no way assent. The following proofs may at any time be tested by Murray in my own furnace and boiler, which are freely used by the coal-owners of Lancashire and other counties for testing the calorific values of their several coals, as before shown. Throughout the following experiments the same coal was used. In No. 1, the air was freely admitted through 342 ½-in. holes in the door-box, as was done at Newcastle, no caution whatever being necessary. In No. 2, these orifices were closed, and the door was the ordinary one as generally used.

| | Coal used. | Water evaporated. | Water evaporated per lb. of Coal. | Pyrometer Heat in Chimney of escaping Product. | Remarks. |
|---|---|---|---|---|---|
| | lbs. | lbs. | lbs. | ° | |
| No. 1 .. | 268 | 2534 | 9·45 | 1212 | No smoke. |
| No. 2 .. | 395 | 1781 | 4·50 | 847 | Much smoke. |

With reference to the absence of economy on the one hand, and the "considerable caution" required on the other, I here quote, in further opposition to both assertions, the words of the three professional umpires at Newcastle—Armstrong, Richardson, and Longridge—on the point of admitting the air at the door-end of the furnaces. In their published reports they say, as to steam generated, "there was a large increase above the standard in every respect." Again, "The prevention of smoke was, we may say, practically perfect." Again, "No particular attention was required from the stoker; in this respect, the system leaves nothing to desire."

"The results show a large increase above the standard in every respect. The prevention of smoke was, we may say, practically perfect, whether the fuel burned was 15 lbs. or 27 lbs. per sq. ft. per hour. Indeed, in one experiment we burned the extraordinary quantity of 37½ lbs. of coal per sq. ft. per hour upon a grate of 15½ sq. ft., giving a rate of evaporation of 5½ cub. ft. of water per hour per sq. ft. of fire-grate, without producing smoke. No particular attention was required from the stoker; in fact, in this respect the system leaves nothing to desire, and the actual labour is even less than that of the ordinary mode of firing."—*Report on Williams' System.*

"Mr. Williams' system is applicable to all descriptions of marine boilers, and its extreme simplicity is a great point in its favour."—*Report of Armstrong, Richardson, and Longridge.*

In further corroboration of these returns, we have also the authority of the two professional gentlemen, Miller and Taplin, deputed by the Admiralty to report on "the evaporative power and economic value of the Hartley coal and Welsh steam-coal." In their report they state that they inspected a modification of Williams' plan for the admission of air into the furnace, and found the prevention of smoke to be almost perfect. Also, that on the 3rd of August they inspected the apparatus in the 'Expert,' steam-tug, and, "as they were on board for several hours, they had every opportunity of seeing the effect of making and preventing smoke; and although there was no very careful stoking, yet the prevention of smoke was *almost perfect*."

Having explained the necessity of considering the calorific or heat-generating property of the coal, apart from the steam-generative property of the boiler, Williams next examines the latter in reference to its heat-absorbing faculty.

In coming to consider more closely the heating-surface of the tubular system, Wye Williams observed, I would first insist upon the importance of increasing the efficiency, rather than the mere gross *area*, of such surface. This should be the first consideration. The area of surface in the boilers of the present day is already greater than would be necessary were it more efficient as a heat-transmitter. Numerous instances indeed might here be given of a very large reduction of the surface having been made by the removal of many tubes without any appreciable result. I have even known boilers to be improved by having several tubes removed and the tube-plate patched over the places from which they were taken out. The accompanying drawing, Fig. 878, of the face-plate of the Holyhead steamer, the 'Anglia,' illustrates a case of this kind. The question of efficiency, as contrasted with mere area of heating-surface, is by far the most important, although, strange to say, it is the most neglected. In this direction alone may we expect the greatest measure of improvement of which boilers are susceptible. The evil of an insufficiency of steam, notwithstanding an ample area of so-called heating-surface, at once raises the question as to the demerits of the tubular system. The prevailing type of modern boilers, whether for railroads or for steam navigation, is characterized as the multitubular boiler. In the multitubular system the heated products pass from the furnace through a series of metallic tubes, varying from 6 to 10 ft. in length, and from 1½ to 3 in. in diameter. The avowed object of this subdivision is to increase the aggregate of surface to which the heat is applied. This system of subdivision of the heated matter is, however, prejudicial both in a

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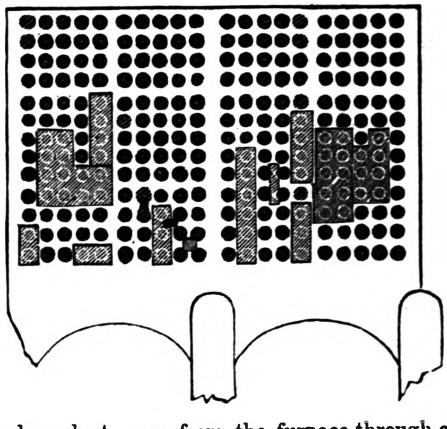


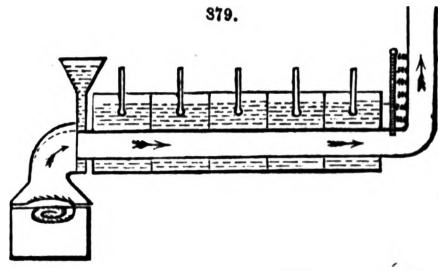
chemical and mechanical point of view, by attenuating its effect. This type of boiler being now so general, an inquiry into its origin is not only necessary in explanation of its adoption, but as a means of tracing and correcting the error into which we have fallen.

The tubular system was first adopted by George Stephenson in the locomotive, the 'Rocket,' by which, in 1830, he won the prize of 500*l.* on the Manchester and Liverpool Railway. The use of tubes in the 'Rocket,' at the suggestion of Henry Booth, the treasurer and most influential member of the company, was then accompanied, *not for the first time, be it observed*, with the passing of the waste steam from the cylinders through the chimney. The result of this combination of tubes and artificial draught was so successful and so unexpected as at once to be considered conclusive, and to leave no room for doubt or inquiry. The steam-jet in the chimney created, in fact, so powerful a draught as to secure an adequate combustion of the fuel, with the generation of a corresponding sufficiency of heat, while the tubes, by reason of the large surface they presented, were assumed to supply the other desideratum—the application of that heat in the generation of steam. Had, however, the two principles been separately applied and examined, and estimated according to their relative and respective merits—which never was done—it would have been found that nearly the whole of the favourable result obtained was really owing to the steam chimney-jet, and the powerful draught it occasioned. The value of the combined action of the jet and of the tubes, however, was taken for granted, and has since been considered the perfection of efficiency.

The value of the steam-jet, and of the increased draught it occasions in locomotives, has been too well established to require any remarks; I will (continues Williams) therefore confine myself to the use of the *tubes*. It is manifest that the main difficulty under which engineers abour, as regards marine boilers, consists in providing adequate heat-transmitting surface. This difficulty early suggested itself to the elder Stephenson. Smiles, in his biography, tells us that his son, the late lamented Robert Stephenson, observed, "Other engines with a variety of constructions were made, all having in view the increase of the heating-surface, as it became obvious to my father that the speed of the engine could not be increased without increasing the evaporative power of the boiler." This inference was strictly correct; his error (hitherto unexamined and uncorrected) lay in the hasty and inconsiderately-formed assumption that an increase in the evaporative or steam-generative power would necessarily be secured by an increase in the tubular surface. This error, therefore, naturally led him to an extension, not only of the number of the tubes, but to give them the length of even 13 ft. So fully was Robert Stephenson impressed with the idea, that he observed, "The power of generating steam was prodigiously increased by the addition of the multitubular system." That this inference was erroneous, is clear from the fact that the 'Rocket' had but twenty-five tubes of 3 in. in diameter and 6 ft. long, and the entire tubular surface had but the insignificant aggregate of 117¾ sq. ft.—an amount of surface which would excite the smile of modern engineers at the idea of its "prodigiously increasing" the generation of steam. The insufficiency of so small an amount of surface to produce any noticeable effect was subsequently demonstrated by the fact that in the Newcastle boiler (to which was applied the apparatus to which the prize of 500*l.* was awarded) an addition of forty tubes with a surface of 320 sq. ft., and placed under the most favourable circumstances for transmitting heat, had but little effect, and could only extract 45° out of 600°—the temperature of the heated products passing through the tubes. "The heater, which was used for the purpose of heating the feed-water, slightly increased the evaporative effect by its additional absorbing surface. This increase was, however, much less than might have been expected from the large absorbing surface of the heater, which contained 320 sq. ft.; yet it was found that, when the products of combustion before entering the heater were at 600°, the passage through it did not reduce the temperature more than 40° to 50°."—*Report of Armstrong, Richardson, and Longridge.* It seems strange that this fact, so suggestive, and so prominently noticed and recorded, did not lead to further inquiry as to the cause of the manifest insufficiency of the heat-transmitting power of the tubular surface; nevertheless, this *combination* of the tube-surface system with the jet remains still unquestioned. "The superiority of the arrangement adopted in the 'Rocket,'" observes Smiles, "consisted in the rapidity of combustion in the fire-box keeping pace with the rapidity of motion in the locomotive itself; for, according as the strokes of the piston in the cylinder were fast or slow, so were also the jets of steam thrown into the chimney on which depended the draught of heated air through the tubes of the boiler, and consequently" (a manifest non-sequitur) "*the amount of steam generated from the water exposed to the large extent of heating-surface* which they presented." Here we see no indication of doubt as to the action of the tubular surface, which is set down as the unquestioned source of the generated steam. The trial with the 'Rocket' took place in 1830, and the supposed steam-generating value of tube-surface remains unquestioned to this day.

"It was not until some years after, when the tubular system was introduced into marine boilers, that I," adds Wye Williams, "began to entertain any doubts as to its merits. Aware of some experiments having been made on the Manchester and Liverpool Railway, I applied early in 1858 to Dewrance, then chief engineer to that railway, and here give his reply to my inquiry. He said:—'In reply to your inquiries as to the experiments made by myself and Woods, about the year 1842, as to the evaporative effect of the *tube* portion of a locomotive boiler, I have to say that we had one of the boilers employed on the Liverpool and Manchester line divided, so as to separate the water in the *tubular* portion of the boiler from that in connection with the fire-box portion. In a subsequent experiment, I divided a small boiler into six different compartments, so that I could ascertain the weight of water evaporated in each. The first compartment was but 6 in. long, the remaining five were each 12 in.—the tubes being 6 ft. 6 in. long. The result was, that each square foot of the heat-absorbing surface in the first compartment was about equal to a square foot of the fire-box surface. In the second compartment each square foot of tubular surface was estimated at about one-third of that value; but in the remaining four compartments the evaporation was so small as to raise a doubt on my mind whether it had any value at all. In fact, I came to the conclusion that the first 6 in. of the tubular series had more evaporative effect than

the remaining 60 in.' Here was ample encouragement for further inquiry, the heat-transmitting property of the tubular surface being so seriously impugned. A similar experiment had been made by the late Benjamin Hick, of Bolton, a competent and able experimenter. The conclusion that he came to was, that each 10 ft. of tube-surface had only the heat-transmitting power of 1 ft. of furnace-surface. My own experience goes far in corroboration of these data, as will presently be seen."




To exemplify these facts, Williams had a boiler so constructed that the heat-transmitting value of each lineal foot of tube should be indicated with absolute certainty. The tube was $3\frac{5}{8}$ in. diameter, similar to those in the 'Eblana' steamer. It was 5 ft. long, and divided into six compartments or separate boilers, as shown in the annexed engraving. Observing that the boiling, which was violent, always appeared to come exclusively from the end next the plate in which the tubes were inserted, the first compartment was confined to a single inch of the tube, the second to 10 in., and the remaining four compartments, each to 12 in. The following is the result after three hours:—

| First Compartment, of 1 inch, evaporated. | Second, of 10 inches. | Third, of 12 inches. | Fourth, of 12 inches. | Fifth, of 12 inches. | Sixth, of 12 inches. |
|---|---|---|---|---|---|
| lbs. oz. | lbs. oz. | lb. oz. | lb. oz. | lb. oz. | lb. oz. |
| 2 14 | 2 15 | 1 14 | 1 6 | 1 2 | 1 1 |

Here we see the first single inch of the tube evaporated nearly as much as the adjoining 10 in., while the first 11 in. did more than the remaining 48 in.

Desiring to place this beyond all question, and thinking that objection might be made to the results obtained from a single-tube boiler, Williams subsequently had a boiler constructed with twenty-five tubes—the exact number of the 'Rocket' boiler—6 ft. long, and $2\frac{1}{2}$ in. internal diameter. This boiler he divided into three compartments, by water-tight partitions placed 1 ft. from either end, thus leaving a central compartment 4 ft. long. Having connected this boiler with a suitable furnace, he found that the water in the first compartment, which received all the heat transmitted through the tube-plate, boiled in twenty-three minutes from the time of lighting the fires; that in the second compartment it took forty-eight minutes to boil; and that in the last compartment it did not boil until fifty-nine minutes had elapsed. During three hours of uniform firing, the following results were obtained. In the first compartment, a foot long, 240 lbs. of water were evaporated; in the second compartment an average of only 70 lbs. of water for each foot of length was evaporated; and in the last compartment, a foot long, only 50 lbs. of water were evaporated.

Having thus established the fact of the great evaporative efficiency of the first compartment of the tube, and especially of the first inch, in length, PRACTICALLY THAT OF THE FACE-PLATE, and the comparative inefficiency of the remaining 5 ft., it became necessary to examine the cause of this extraordinary result, to find out how it happened that a stream of heated products at a temperature above 600° passing continuously for three hours through the tube, was incapable of transmitting more heat to the last 12 in. of its length than could keep the temperature of the water at 180°. In the fact that it was so, we at once see the inutility of increasing the length of the tube. Let us first examine the area of heating-surface in a few vessels of the largest class. The published authoritative account of the American iron-clad floating battery, by Mr. Stevens, gives the following details:—

| | sq. ft. |
|---|---|
| Tube-surface | 23,380 |
| Furnaces | 2,050 |
| Connexions | 1,890 |
| Tube-sheets | 680 |
| Total | 28,000 |

Here the gross area of tube-surface is estimated in the same category with that of the furnace-surface. Now, in taking the true value of tube-surface as stated by Dewrance, or Hick, these nominal 23,800 sq. ft. would be at once reduced to 2380; and this most probably is not far from the truth. Again, take the tube-surface of the late Brunel's boilers in the 'Great Eastern' (which are constructed on the same principle as the original boilers of H.M.S. 'Terrible') for each set of twenty-four furnaces (there being 112 in all) at 6000, and of furnace-plate at 3000 sq. ft.—say 28,000 ft. of tube-surface in all—and then see what a serious, though unsuspected reduction should be made in reducing those 28,000 ft. nominal, to effective heat-transmitting surface. Under such circumstances we cannot doubt the imperious necessity of the furnace-forcing system. Again, let us examine the tube and furnace surface of one of the Holyhead steam-packets of 750 nominal horse-power:—

| | |
|---|---|
| Tube-surface in eight boilers, with 40 furnaces, in square feet | 15,600 |
| Furnace ditto | 1,960 |
| Back, side, and top of uptake | 1,108 |
| Tube-plates between the tubes | 316 |
| Total | 18,984 |

We here see again how much larger in proportion is this nominal *tube*-surface than that of the *furnace*, and how much more serious is any default in its efficiency, there being in this case 20¼ superficial feet of tube-surface per nominal horse-power. In these boilers the tubes are 6 ft. 2 in. long, and but 2½ in. diameter.

Again, we have the iron-clad steam-vessel, the 'Warrior,' the type of whose boilers, according to the published accounts, is identical with that of the Holyhead steam-packets, but with both tubes and grate-bars 6 in. longer. In this vessel there are no less than 4400 brass tubes of 6 ft. 6 in. long by 2¾ in. inside diameter. In the new war-vessel, the 'Octavia,' we have the same identical type of boiler, and excess of tube-surface.

In opposition to all this, Williams stated that in one of the most efficient boilers, as regards the sufficiency of steam, in the fleet of the City of Dublin Company, the tubes are but 3 ft. long, and the relative proportion of tube-surface to flue-surface is but as $2\frac{8}{10}$ to $6\frac{1}{10}$ the nominal horse-power. The contrast is most remarkable. The merit of that boiler doubtless arises from the circumstance, that the shortness of the tubes leaves a large chamber for the combustion of the gases to complete itself in before the products approach the tubes.

Now, how are we to account for the fact that the several designers of the boilers before spoken of have adopted almost identically the same description of boiler, with the same objectionable features? At first sight, it would appear that all had been convinced of its practical superiority. This would be a reasonable inference had it been the result of well-established experience. No experiments, however, having been made for testing the heat-transmitting power of tube-surface, apart from other considerations, we have no alternative but that of attributing this singular coincidence to the desire of avoiding that responsibility which would attach to any great deviation from existing practice. Here, however, we have, in all, the same objectionable length of furnace-grates—the same absence of all means of admitting air to the generated gases—the same want of space between the fuel and the tube-face plates—and the same absence of a combustion-chamber, although all improved locomotive engineers are studious in providing such means of promoting the use of coal on the railroads.

The great error into which we have fallen, in the absence of experiment, is an over-estimation of the heat-transmitting property of the tube-surface. In our calculation of the steam-generative power of the boiler, we assume it to be always proportional to the number of square feet of the surface exposed. Now, this calculation is made without reference either to the rapidity with which the current of heated products passes through the tubes—to the diminishing rate at which the tubes transmit heat in proportion to their length—or, worst of all, to the direction in which these products strike or impinge upon the tube-surface. If it were true that each square foot of metallic surface really possessed a given or known amount of heat absorbing and transmitting power, whatever that might be, an increased number of square feet would necessarily represent a commensurate increase of the steam-generative power. The real value of the so-called heating-surface, however, depends on so many contingencies, that calculations based on the mere gross area of surface exposed must be utterly valueless. We have here, then, the important question raised,—What value are we to attribute to such surfaces? The single fact of the very high temperature of the escaping products in the chimneys of marine boilers, is alone conclusive of the deficient heat-transmitting faculty of the surface of the tubes. Our purpose, then, should be, not to increase the number or length of the tubes, or the sum of their surface-areas; but to render these surfaces more effective as heat-transmitters. In manifest neglect of this purpose, we find in the boilers of the most recent construction, and even in war-vessels, the greatest possible number of tubes, and of the greatest length, crowded together without regard even to the water-spaces between them, which are often restricted to but half-an-inch. The result is, that in the absence of sufficient water-spaces, particularly at the end where the heat first strikes the face-plate, the tube-ends are exposed to the greatest heat, and they soon begin to weep; the face-plate itself begins to crack, and the space where the water should have the freest circulation becomes choked up with the solid matter of incrustation. Samples of this matter here exhibited afford sufficient proof of the fact.

Wye Williams remarks that, in a recent publication, we are told that "marine boilers require 5 sq. ft. of heating-surface, and one-fifth of a square foot of fire-grate surface for every indicated horse-power." Here is a calculation supposed to be based upon some reliable data; we shall see, however, that all such calculations are but as the "baseless fabric of a vision." It may be asked, indeed, if the writer had ever inquired what the value of a square foot of heating-surface, or of fire-grate surface, really was? Yet, from the affected precision of the author in other respects, we might be led to suppose that both had been reduced to some standard, or in fact were constants. Nothing, however, can practically be more vague and misleading. The value of a square foot of fire-*grate* surface, for instance, will depend: first, on the nature of the coal as bituminous or otherwise; second, on the quantity of gas it produces; and third, on the amount of draught passing through the furnace from the ash-pit. On the other hand, the value of a square foot of *heating*-surface will depend mainly on the direction in which the current of heated products obtains contact with the metallic surface. This last, though the main element of success, yet, strange to say, is the very one which is not only overlooked, but absolutely ignored in all modern practice.

Of the practical errors committed in the mode of estimating the steam-generative value of the tube-surfaces, we have an instance in a recent publication professing to give the results of the most improved systems, where it is stated, as a leading principle, that direct impact with the heat-absorbing surfaces should be *avoided*. That this is a prevailing error is confirmed by Robert Murray, who, in one of his publications, has laid it down as a principle, that "*elbows are to be avoided*"; in other words, that the current of heated matter passing through flues or tubes should not be broken, bent, or interrupted, or the straight line of their course disturbed. Now, said Williams, in the paper from which this extract is taken, I am prepared to prove, on the contrary,

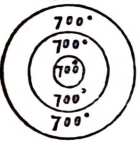
that the direct reverse of this instruction is essential to success; and upon this I insist. If the author had said, that the direct impact of *flame* should be avoided, with the view of preventing the formation of smoke and soot, he would have stated a correct chemical fact. Direct impact of the heated products, *after* the combustion of the carbon of the flame, is, however, precisely what should be promoted. Practically, it will be shown that the absence of direct impact is the main source of inefficiency of modern tubular boilers, and the cause of that great escape of heat by which the uptake and chimneys of marine boilers are so over-heated and destroyed. And in this respect, I hesitate not to say that the multitubular system is largely and radically deficient in the heat-transmitting faculty. The main point, then, for consideration is, how to make any given surface more effective as a heat-transmitter, and what are the conditions on which the transmission of heat depends. This, *cæteris paribus*, as regards the rate of current of the heated products, will depend on the direction in which those products are brought into contact with the plate or tube-surface—whether by a *direct*, *diagonal*, or *parallel* action. On this point it may be stated, as the result of actual observation and experiment, that a square foot of surface on which the heated current strikes with a direct impact (that is, at right angles to the surface) will be equal to 4 ft. where the direction is diagonal, and to double that where the current runs parallel, or in the same plane as the metallic surface. In estimating the action of a heated current passing through tubes, we ordinarily overlook the fact that gaseous matter (that is, the products after combustion), whatever may be its temperature, radiates but little, if any, heat. Radiation can alone proceed from solid matter. It is this which enables visible flame to radiate so powerfully; visible flame being merely an aggregate of myriads of solid carbon atoms, still unconsumed, and at a white heat, or, as estimated by Davy, at 3000°. Now, the products of flame, after combustion, and when passing through the tubes, are transparent, and transmit little or no heat by radiation. It is by their contact alone with the metallic surface that heat is communicated and transmitted.

Again: that but little heat is transmitted when smoke is formed in a flue or tube, Williams goes on to say, I have repeatedly proved, by the introduction, through the smoke-box, and into the tubes, of an iron rod, to the end of which were attached pieces of paper and shavings. After remaining some time, they have been withdrawn, yet, although their *outsides* have been covered with black soot, their *insides* have not even been discoloured by heat. When, therefore, we see a volume of smoke issuing from the chimney, we may be assured that the tubes are full of it, and that the temperature within them is not much greater than the hand could bear.

Let us now suppose a column of heated products entering and passing through a tube, as a cylindrical shot does through a cannon. Contact is then alone obtained between the outside section of such column and the metallic surface. This section having given out as much heat as possible in the fraction of a second (the time which its transit occupies), the interior portion of such column passes onwards undisturbed, carrying its initial temperature to the exit. In no other way can we account for a column of products above 600° of temperature, passing continuously, and for hours, through and along the interior surface of a tube, and yet giving out no more heat than can keep the water at 180°.

Let Fig. 880 represent a longitudinal section, Fig. 881 a cross-section at the entrance, and Fig. 882 a similar section at the exit of a tube. The several lines are here supposed to represent the sections or strata of the heated products passing through it, entering at a temperature of 700°,

881.

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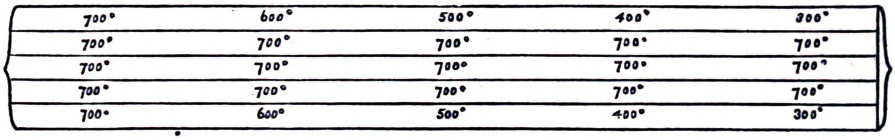


882.

and issuing at 540°. In this case, the outer section, being next, and in contact with, the iron-tube surface, will give out heat, and be reduced, say to 300°, on arriving at the end of the tube. But what is to cause any interchange of position between it and the other strata?

To sum up the objectionable features of the tubular system—as exhibited, for example, in the accompanying diagram, Fig. 883, which represents a boiler of the modern type, as fitted in a large packet belonging to the City of Dublin Steam-Packet Company—they consist: 1st. In an extreme length of fire-bar surface, often amounting to above 7 ft., a length which absolutely precludes the possibility of a stoker keeping the back-end sufficiently covered by fuel. 2nd. In long shallow furnace-chambers, in which the solid fuel on the bars necessarily occupies the entire space, reaching to the very crown-plates, as shown in the diagram—an arrangement by which neither time nor space is allowed for that gradual mixing and diffusion of the air with the gas generated from the mass of fuel, which are the *sine quâ non* of perfect combustion: in this respect we have the ordinary practice directly opposed to the sound conditions stated by Mr. Murray, when he describes the value and necessity of "large and high furnaces." 3rd. In the absence of due provision for the admission of the air either in suitable quantity, proportioned to the large evolution of gas, or in a manner adapted to its admixture and diffusion with the gas. 4th. In long and shallow ash-pits, by which the air, instead of gradually ascending through the bars from front to rear, is forced into a rapid current towards the farther end, where it is forced upwards with increased velocity, through the fuel on the farther ends of the bars, with the force of an artificial blast, causing a rapid combustion in that quarter, and thus leaving the bars uncovered, and the air free to pass upwards in a mass. 5th. In the absence of provision for the admission of a supplementary quantity of air behind the bridge. It is evident that where the furnace is long and shallow, as in Fig. 883, the fuel considerable, and the gas evolved necessarily great in quantity, any air that could possibly be

introduced at the door-end must be wholly insufficient for the combustion of that gas. In such cases, the required quantity of air must be supplemented from the ash-pit and behind the bridge. The engraving, Fig. 884, shows the mode in which this was effected, and the air introduced through a series of ½-in. holes in one of the City of Dublin steam-packets, and with decided success. The

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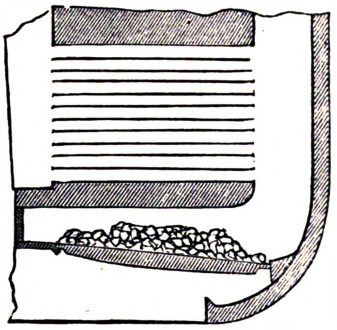

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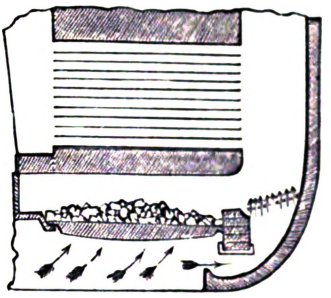


cost of the apparatus was too insignificant to merit attention. 6th. In the want of sufficient space between the bridge and tubes, as a chamber in which the necessary admixture of the air and the gas may be effected for combustion. Experience proves that, whatever may be the construction of the furnace or the boiler, a distance of from 6 to 8 ft. is absolutely necessary for that purpose. In this respect, boilers on the plan of the 'Great Eastern's' are peculiarly objectionable, no space whatever being allowed for the combustion of the large volume of gas generated from each of two long furnaces, which meet at the middle, and practically form one furnace of 18 ft. in length. The result is that much of the gas passes unignited and unconsumed through the tubes, to be ignited at the wrong end, and in the smoke-box, where it meets with a supply of air coming from those other furnaces in which the fuel at the time happens to be in a clear state, and their bars to a great extent uncovered. 7th. In an unnecessary and injurious length of tube, which is but slightly instrumental in producing steam, as will hereafter be shown, while it occupies a large space, much of which might have been appropriated as a chamber for the combustion of the gas, as is done in the most approved locomotives. 8th. In the absence of sufficient space for the presence and circulation of the water between the tubes, and especially at the end nearest the face-plate, against which the flame strikes with peculiar energy. In this respect, the marine tubular boiler labours under a serious disadvantage from which the locomotive is exempt. In the latter, the space occupied by the tubes and the furnace compartment is separate, the steam generated from each having its own proper place for its ascent. In the marine boiler, however, the tube series being placed directly over the furnaces, the great mass of steam generated directly from the latter has to work its way in its ascent through spaces which are not above ½ or ¾ of an inch between the tubes. The result is that the tubes are surrounded by the mass of steam rising from the furnaces, and which practically drives the water before it, leaving the tubes without any. In this respect, the system is again directly the reverse of that very properly insisted on by Robert Murray, when he says, "that the steam should have a ready escape from every part of the heated surface." In the marine boiler we see that, instead of a ready escape, it has the greatest mechanical obstructions to contend with.

I must be allowed here to remark that the evils which I have pointed out are not peculiar to the boilers of any particular vessel, or set of vessels, but are to be found, on the contrary, in many of the finest and best ships in existence, including the 'Warrior' and 'Octavia' men-of-war, the fast Holyhead packets, and many other first-class vessels. It is not, then, to be wondered at that the coals most in favour are not those which would give the greatest calorific effect, if duly consumed, but such as would avoid the issue of dense smoke, and thus give the appearance of economy. It will be presently shown that the absence of smoke, in some descriptions of Welsh coal, is no proof of greater heating powers, or of a more economic fuel.

Looking, then, at the comparative inefficiency of the tubes, as steam generators, with the exception of the first 12 or 18 in. (which includes the action of the *face-plates*), and looking also to their peculiar position, we see them in the very place which, mechanically and chemically, is most appropriate for the combining action of the gas and the air—in a word, for a combustion-chamber. There appears, then, no alternative but that of dispensing with the use altogether of long straight tubes or flues. In truth, we cannot separate the existence of straight tubes from the vice of having the current of heated products passing in the same plane and direction as the surface through which the heat is to be transmitted. In this abandonment of the straight-tube system, it must be confessed that there are commercial difficulties which, it may be feared, will materially retard this useful change. On discussing the subject with a well-known engineer, and showing him, practically, the inutility of the tube-surface, particularly where long tubes are used, Williams continued to say, I was struck with the difficulty of obtaining his assent, while all other witnesses expressed their entire conviction in what they saw produced in the experimental boiler. On his departure, however, the mystery was solved, and my surprise at an end, when I was informed that he was largely connected in Birmingham, and even with a patent for an improved mode of welding them. It was thus manifest that personal interest was directly opposed to change, conviction, or improvement. I may here add that I understand several engine and boiler makers are in the same position, and have largely invested capital in the manufacture

of tubes. This, while it accounts for the difficulty in the way of improving our boiler system, increases the fear of its requiring a lengthened period before the necessary change and improvement shall be realized.

Under these circumstances, I may perhaps be permitted to suggest that the Admiralty, who can have no personal interest in the manufacture of tubes, have it in their power to do the public a most essential service by instituting inquiries into those practical defects of the tubular system to which I have drawn attention, and by lending their high influence to remedial changes. It would be a great stimulation to the progress of marine engineering if they would do this, and would, at the same time, institute more complete and satisfactory tests of their steam-ships. Either in place of, or in addition to, the ordeal of the measured mile, let them institute lengthened runs at sea, as is done with Clyde-built vessels, where the trial-trips generally involve a run from Greenock to Liverpool. In these trials let the Admiralty require official returns involving the following particulars:—1st. The speed *an hour;* 2nd. The actual weight of coals used *an hour;* 3rd. The degree to which smoke is produced or avoided; 4th. The temperature of the stoke-hole; 5th. The temperature of the escaping products in the uptake, ascertained by the pyrometer; 6th. The weight of clinker and its peculiarities; and 7th. The weight of incombustible ash. The inspecting officer should also be required to report upon the extent to which forcing of the fires may have been resorted to.

It will be observed that these returns involve the qualities of the fuel employed, and of its fitness for use in the furnaces of the particular ship tested, as all such returns undoubtedly ought to include these particulars. In order to show that there is no great difficulty in obtaining such particulars, I may mention that they are all attended to in the tests of coal, made by their respective owners, in the test-boiler of the City of Dublin Steam-Packet Company at Liverpool, and are all so easily and accurately determined that the tests in question at once stamp the true character of each description of coal. In illustration of these results, I here give a return of ten kinds of coal, with their several calorific values taken from the results of some of the tests just mentioned.

TESTS OF COALS AS MADE IN THE BOILER OF THE CITY OF DUBLIN STEAM-PACKET COMPANY.

| Denomination of Coals. | Total Water evapo-rated. | Total Coals con-sumed. | Total Time em-ployed. | Coal con-sumed per hour. | Water evapo-rated per hour. | Water evapo-rated per lb. of Coal. | Pyro-meter heat in Flue. | Tempera-ture of waste Heat in Chimney. | Clinker per cwt. of Coal. | Ash per cwt. of Coal. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | lbs. | lbs. | H. M. | lbs. | lbs. | lbs. | o | o | lbs. | lbs. | |
| 1 Welsh. | 8000 | 980 | 3 47 | 259 | 2114 | 8·16 | 1083 | 484 | 3·08 | 1·14 | No smoke from any of the Coals, the combustion being made perfect in each case by the proper admission of air. |
| 2 Welsh. | 8000 | 898 | 4 30 | 199 | 1777 | 8·92 | 831 | 450 | 4 37 | 1·88 | |
| 3 Welsh. | 8000 | 952 | 4 57 | 192 | 1616 | 8·40 | 739 | 450 | 5·17 | 1 88 | |
| 4 Welsh. | 8000 | 784 | 4 41 | 167 | 1707 | 10·20 | 957 | 466 | 2·14 | 2·00 | |
| 5 Lancashire. | 8000 | 1008 | 3 34 | 278 | 2242 | 7·93 | 1126 | 517 | 1·73 | 0 69 | |
| 6 Lancashire. | 8000 | 896 | 3 42 | 242 | 2162 | 8·92 | 1079 | 535 | 2·78 | 0 34 | |
| 7 Lancashire. | 8000 | 896 | 3 35 | 250 | 2232 | 8·92 | 1200 | 574 | 2·50 | 1·12 | |
| 8 Sundries. | 8000 | 1064 | 3 51 | 276 | 2077 | 7·51 | 1099 | 500 | 4·10 | 1·36 | |
| 9 Sundries. | 8000 | 1064 | 3 27 | 309 | 2318 | 7·51 | 1157 | 524 | 1·42 | 1·00 | |
| 10 Australian, per 'Royal Charter.' | 8000 | .. | .. | 239 | 1783 | 7·46 | 1115 | .. | 0·49 | 1·71 | |

"The above test-trials were made at the request of the owners of the respective collieries, for the purpose of ascertaining the calorific value and peculiarities incident to each coal, as regards clinker, ash, &c. The names of the collieries or owners are purposely omitted, as the returns of any one kind of coal are never communicated to those of any other kind."—WILLIAM BALFOUR M'ALLISTER, *Foreman Boiler Maker to the Company.*

These only embraced the returns of the last nine months, and the tests were all made at the request of their respective owners, on opening new beds in their collieries. Wye Williams adds, I suppress the names of the different coals to avoid giving unnecessary offence to any of the proprietors. It will be observed that as there was no smoke from any kind of coal, and perfect combustion effected, the full calorific effect was obtained in every instance. This was also confirmed by the appearance of the furnace, as every part of the interior was made visible by means of properly-placed sight-holes, as was the case in the Newcastle experiments. These returns show the error of estimating the so-called evaporative power of the coal by reference to the water evaporated by each pound weight of the coal. We even find that the description which gives the largest return in that respect, may, in fact, be the worst adapted for steam-generative purposes, inasmuch as the time occupied is so much greater. This element of time is of the highest importance, as regards the providing an adequate supply of steam for the cylinders. Take, for instance, No. 4. There the amount of water evaporated to a lb. of coal was 10·20 lbs., yet there were but 1707 lbs. evaporated *an hour*—during the time required for the evaporation of the tank full, of 8000 lbs.—say, in all, four hours forty-one minutes. Whereas, in the case of No. 7, though there were but 8·92 lbs. evaporated *to a lb. of coal*, there were no less than 2232 lbs. evaporated *an hour*, the 8000 lbs. being evaporated in three hours thirty-five minutes. A further illustration of the importance of attending to the *mode* in which the several kinds of coal enter into combustion, as Percy has well observed, is shown in the following returns, where five kinds of coal were tested, and the temperatures in the flues and of the escaping products were both noted:—

HEAT DEVELOPED PER CHARGE OF 56 LBS. COAL, SHOWN BY THE PYROMETER IN THE FLUES INDICATIONS.—TIME, 20 MINUTES.

| No. 1. Swansea. | No. 2. Newport. | No. 3. Coed Talon. | No. 4. Powell's Duffern. | No. 5. Main Depth. |
|---|---|---|---|---|
| [740 | 753 | 1000 | 835 | 1120 |
| 750 | 725 | 1045 | 845 | 1150 |
| 760 | 720 | 1035 | 850 | 1225 |
| 765 | 725 | 1060 | 855 | 1255 |
| 775 | 735 | 1075 | 860 | 1280 |
| 785 | 745 | 1075 | 870 | 1290 |
| 795 | 755 | 1080 | 900 | 1295 |
| 805 | 765 | 1080 | 920 | 1300 |
| 825 | 775 | 1095 | 925 | 1300 max. |
| 835 | 790 | 1095 | 945 | 1280 |
| 840 | 805 | 1095 | 955 | 1250 |
| 850 | 815 | 1100 | 970 | 1225 |
| 855 | 825 | 1100 | 975 | 1220 |
| 865 | 830 | 1100 | 980 | 1200 |
| 875 | 845 | 1110 | 990 | 1155 |
| 885 | 855 | 1120 max. | 1000 | 1130 |
| 895 | 865 | 1110 | 1000 | 1110 |
| 905 | 875 | 1115 | 1005 | 1100 |
| 910 | 890 | 1105 | 1010 | 1075 |
| 910 max. | 895 max | 1075 | 1020 max. | 1050 |
| 20)1662·5 | 20)1598 5 | 20)2167·0 | 20)1871·0 | 20)2401·0 |
| 831° | 799° | 1083° | 935° | 1200° |
| *Average Waste Heat in Chimney.* | | | | |
| 450° | 450° | 484° | 397° | 574° |

In Nos. 1, 2, and 4, of the annexed Table the largest development of gas, and consequently the highest temperature (assuming that perfect combustion was realized), was at the *end of each* charge of twenty minutes (the temperatures were taken at intervals of a minute), whereas, in Nos. 3 and 5 the maximum temperatures were attained at the end of sixteen minutes and eight minutes respectively. This latter is the coal preferred by the Dublin Steam Company. Williams adds, I am sure it will be acknowledged that these tables contain much valuable information which is omitted from the official returns required by the Admiralty when steam coals are tested for them. In those returns no account is taken of the gross time employed in the evaporation of any gross weight of water; neither are we told what temperature was obtained for evaporative purposes; nor what escaped in the state of waste heat; nor how far combustion was perfect, as indicated by the presence or absence of smoke in the chimney. We see in them no indication of the use of that valuable and all-important instrument the *pyrometer*, without which it is impossible to form any correct estimate of the calorific or commercial value of any kind of coal.

Feeling so deeply the inefficiency of the tubular system as now generally adopted, I have endeavoured to substitute for it some more effective one, bearing in mind, of course, the necessity (to which I have before referred) of ensuring the direct action of the hot products of combustion upon the heating-surface. My endeavours in this respect have not been successful. I have arranged a form of tube, or rather flue, which presents a series of surfaces against which these hot products will strike at right angles, or nearly so, and consequently transmit a larger quantity of heat to the water in the boiler. As this, however, would be of comparatively small effect, unless accompanied by other material changes in the details and construction of the boiler, and the removal of the several evils already enumerated, I propose here detailing those alterations and principles, with their influence, chemically and practically, which go to the formation of a perfect boiler and its furnaces, namely:—

1stly. That in the construction of a boiler, the proportions of its several parts, in particular, its length, from the door to the back-end, should be determined by considerations based on giving effect to those processes and principles on which the combustion, chemically considered, of the constituents of fuel—solid and gaseous—depends. Without regard to this common sense view of the subject, the length of boilers is usually determined by the mere area or space allowed by the actual width of the vessel. This injudicious proceeding appears to have been adopted for the sole purpose of introducing the greatest number of boilers into the smallest possible space—the steam-generative property of a boiler being assumed to depend on the length and area of the fire-grate surface, and wholly irrespective of the chemical process of combustion to be carried on. This at once leads us to the inference that the distance between the fuel at the bridge and the tubes should never be less than from 6 to 8 ft. lineal—experience having shown that it is impossible to effect the perfect combustion of the gaseous constituents of the coal in a shorter space.

2ndly. That where the furnace-bars are above 4 ft. in length, from the dead-plate to the

bridge, and where the chamber is less in height than 2 ft. from the dead-plate to the crown of the furnace, there should always be provided the means of introducing a supplemental supply of air to the gases passing over the bridge. The mode adopted (see Fig. 884) in the Holyhead steam-packet, by a cast-iron plate with a sufficiency of half-inch orifices, has been found as successful as could be expected, looking to the great space occupied by the tubes, and the consequent absence of an adequate combustion-chamber.

3rdly. That tubes should never exceed 3 ft. in length, experience having supplied unquestionable proof of the comparative inutility, as heat-generating surface, of any greater length, while it seriously curtails the space that might otherwise be occupied as a combustion-chamber.

4thly. That the steam generated by the heat from the side and crown plates of the furnace should not be allowed to ascend through the tubes, or interfere with the steam generated from the latter, as already mentioned; but that it be directed to pass upwards through the spaces between the several separate stacks of tubes.

5thly. That the waste heated products from the several furnaces should not be directed into one common receptacle or smoke-box, as is done in the 'Great Eastern' and 'Warrior'; but that the furnaces, being set in pairs, their products should be kept in pairs, until, passing through the uptake, they arrive at the base of the chimney. The reasons and proofs which influence this arrangement are numerous, but cannot be here detailed for want of space.

6thly. Boilers should be so placed that the furnace-doors should face the fore part of the ship, by which the material draught caused by its velocity would come in aid of the direction of the air into the ash-pits, and through the apertures in the furnace-door boxes.

In reference to *Priming*, Murray observes:—"When the ebullition inside a boiler is so rapid and violent that water rises with the steam, and is carried over with it to the engines, the boiler is then said to prime. Besides the danger to the machinery which always attends this propensity, it entails a serious loss of heat, carried off by the water which boils over or is forced up the waste-steam pipes." If this be a correct description of the process of priming, the tubular system has much to answer for the evil, as being peculiarly subject to this "propensity." In consequence of the violent transmission of heat, caused by the large surface of the face-plate exposed to the direct action of the flame, as already described, there is the greatest tendency to that local and violent ebullition by which the liquid matter is forced upwards, and which is no doubt the main source of priming. It may here be observed, however, that the idea of a "serious loss of heat carried off by the water" is erroneous, and arises from the supposition of the water being heated, and having absorbed a given quantity of heat. Now, so long as the water particles retain their liquid form, they have taken up no heat, and can, therefore, carry none along with them. Williams here remarked, "I am sorry to have to refer to a work of my own, but I have taken so much pains to establish this doctrine in my recent work, 'On Heat in its relation to Water and Steam, embracing New Views of Evaporisation, Condensation, and Explosion,' that I trust I shall be excused for referring to it here." The true loss and injury occasioned by the water being carried over in the process of priming, arises—1st. From the liquid particles taking up heat from the inside of the cylinder into which it is carried, and by which a cooling effect is produced; 2nd. From the particles carrying a large portion of the salt and other impurities with which the water may be impregnated, and which to a considerable extent produce an injurious effect upon the valve-facings. "Priming," Mr. Murray adds, "may arise from a variety of causes; but the usual one is a too contracted steam-space over the water of the boiler. For where the reservoir of steam from which the engines are supplied is very small, there must be constant pulsations of pressure in the boiler; and each time that the surface of the boiling water is relieved of a certain amount of pressure by the rapid withdrawal of a cylinderful of steam, it boils up with great violence." This is unquestionably true. It must not, however, be forgotten that the prevailing practice of using higher pressure, and cutting it off, for the sake of *expansion*, greatly increases, if it does not produce, this very serious evil of a constant pulsation of pressure. We cannot, therefore, have the benefit of the expansion principle carried, as it now is, to so great an extent, without the concurrent evil of having the liquid matter carried even into the cylinder by these frequent pulsations. This is peculiarly the case where the cylinders are large and the expansion process is carried out to a great extent.

I must, however, says Murray, insist on the fact, that the violent local ebullition, peculiar to the tubular system, produced immediately behind the face-plate, as already explained, is the main source of the evil of priming. This is well exemplified in the case of new boilers, and on their first trial. The face-plate being then clean, both inside and outside, and the water-spaces being fully charged, and without obstruction to the water's circulation, the transmission of heat through that plate is at its maximum; and the generation of steam greater there then than it ever can be afterwards. The violent ebullition immediately behind the face-plate is far in excess of what can be conceived by those who have not had the means of personal inspection. None but an eye-witness could have an adequate idea of this local action, or of the mass of water thrown up immediately behind the face-plate, with the spray driven off in large quantities; while the other parts of the water-surface are comparatively tranquil, or exhibiting but the ordinary effect of moderate boiling. It was this fact which first drew my attention to the action of the face-plate. I observed that the boilers of the 'Warrior,' like those of too many other vessels, were reported to have been exposed to priming on their first trial; and when I look at the immense extent of face-plates in which the 4400 tubes are inserted, I cease to wonder at the violence of the local ebullition, or at the priming which resulted from it. As the continued use of a boiler causes a considerable diminution of water-space in the rear of the face-plate, by the incrustation which is there rapidly produced, on account of the great heat to which it is exposed, we can readily explain the subsequent diminution of priming when the boiler has been some time in use.

Hitherto we have had no sufficient explanation, chemically or otherwise, of the cause of priming. When, however, we examine closely the act of ebullition, we shall have no difficulty

in comprehending the *rationale* of the process by which the water particles are thus separated and thrown up, and carried by the force of the current out of the boiler. Each bubble formed in a liquid is a spherical or semi-spherical mass of aëriform matter. In the case of boiling water it is of *pure steam* enclosed in a spherical envelope of liquid particles, formed by the repellent force and divergent action of the several steam particles. The *liquid* particles, on the other hand, by reason of their individual attraction and cohesion, sustain that continuity which forms the envelope. When each globe or envelope bursts, the liquid particles of which it is composed are scattered, and, as it were, exploded, and then carried forward to the cylinders. Looking, then, to the violence of ebullition, and the quantity of liquid spray thrown up immediately behind the face-plate, and in no other place, we are enabled to appreciate the source and nature of priming, and the part which the tubular system and its face-plate act in producing this result. The pulsations, then, spoken of by Murray, are not by any means the main cause of priming, but are merely secondary to that violent and local ebullition so peculiar to the action of the face-plate. We see this result of ebullition in the common operation of distilling water for chemical purposes. When the distillation is carried on rapidly, and the water is made to boil violently, the so-called distilled water is found impure to such an extent as to require a repetition of the process, and a double or treble distillation. To obtain pure water from the still, the heat should not be allowed to exceed 200°, when ebullition begins.

On the subject of *Superheating* there seems to be much confusion. The term "superheating the steam" necessarily implies an increase in its temperature. When, however, we examine the operation, we find that, practically, we merely increase the quantity of available steam. Steam, as an elastic fluid, resembles air as regards the difficulty of increasing its temperature; so that anything to be gained in this respect from the action of the heated products passing to the chimney, as waste heat, must be very insignificant. In truth, all we do by the process is to vaporize the liquid particles, which, more or less, always accompany the steam generated from water at what is called the boiling-point. If a given quantity of steam in the boiler contains, say 10 per cent. of liquid particles, their conversion into steam is of equal value with the vaporization of any other 10 per cent. of the water in the boiler. In addition, however, it has the further advantage of relieving the cylinders from the presence of so much liquid matter. In high-pressure engines, as in locomotives, this is not of such importance, inasmuch as the liquid particles are driven off with the steam as each cylinderful is discharged. In the case of *condensing* engines, however, the advantage arising from the absence of liquid matter, and what is termed dry steam, is considerable.

"All boilers," Murray observes, "are subject to the loss of a certain quantity of heat contained in the water which passes off with the steam in the shape of a fine spray. When much of this mixes with the steam, the latter is said to be 'wet'; but it is believed that all steam raised in the ordinary way is thus more or less charged with water in a state of fine subdivision." This has already been considered when speaking of priming. Murray goes on to say:—"To evaporate" (more correctly speaking, to *vaporize*) "and utilize this water is one of the principal advantages of surcharged or 'superheated' steam." He might have gone further, and have said that this is the *sole* advantage gained by this much-extolled process. That this is even Murray's opinion may be assumed from the following brief, and, we believe, just summary, namely:—"The very high rates of economy are shown by those boilers which were previously the worst to keep steam with, and which required very hard firing to do so; those addicted to priming and wet steam rank next in apparent economy; while those boilers that show the least were originally the best specimens of their class." This at once raises the question whether it would not be better to have the boilers so constructed that they should have no spare heat to be so applied; for whatever heat is so applied would have been more economically and efficiently employed in generating steam in the first instance, rather than in being allowed to escape, as waste heat, for the employment of which this superheating process, and the other process of heating the feed-water, have been invented. Whatever degree of success accompanies either of these processes will, in fact, be in the ratio of the waste heat; that is, in proportion as the boiler is deficient in the legitimate application of the heat generated by the combustion of coal. Thus, the more imperfect are the boiler and its furnaces in promoting perfect combustion, and thus realizing the full calorific power of the fuel, and in applying the heat so generated, the greater will be the apparent advantage of heating the steam of the feed-water.

Robert Murray being selected from among many modern engineers who entertain similar views respecting boilers, it is only right to add R. Murray's reply. Writing to the secretary of the Inst. of N. A., Murray said:—"Having been unable to attend the last meeting of the Institution of N. A., I am glad to be allowed this opportunity of replying very briefly to Mr. Wye Williams's remarks upon certain portions of a paper of mine, read before the Institution in the spring of 1860. While doing so, I would wish to express my hearty appreciation of Mr. Williams's long and valuable labours in the peculiar branch of engineering science to which he has so ardently devoted himself; but, at the same time, I must confess to a doubt whether he is not riding his hobby rather too fast. It is my lot to see many pet contrivances and fondly-cherished theories sent off from this port of Southampton on a cruise into the wide world; and of these, when separated from the fostering care of their parents, very few indeed ever live to come back. This sad spectacle, in place of enlarging our sympathies, tends I fear to make us practical men only the more hard-hearted and unbelieving. I admit, however, that a little poking by such men as Mr. Wye Williams is good for us. I shall now attempt to meet some of Mr. Williams's objections.

"With regard to the much-vexed question of 'smoke-burning,' I still maintain that in the furnaces of a marine boiler 'it is not always an economical process'; and further, that 'considerable caution is necessary for the due regulation of the quantity of air to be admitted for this purpose.' It is of course apparent to every one, that the furnace demands a large quantity of

atmospheric air at each recurring period, when the fresh charge of coal is undergoing the process of distillation, and therefore parting with its gaseous constituents. This state of the furnace, however, lasts for only two or three minutes out of every ten; and if the rush of cold air were to be continued after the fire has burnt clear, and there is only incandescent carbon on the bars, a most damaging effect would be produced by the cooling of the flues and tubes. It becomes, then, a practical question, whether the quantity of air to be admitted can be readily and properly adjusted to the condition and requirements of the fuel in the furnace. That with an experimental boiler worked by trained stokers, either on shore, or on board ship, this can be done so as to show a high degree of economy, no engineer will doubt; but the question still remains, Can we place sufficient dependence upon the ordinary fireman to be found on board a steamer, as to leave it in their power to inflict a serious injury upon the boilers by their stupidity or neglect; or will it not be preferable to adopt some simple and fixed arrangement for this purpose, which will not be dependent for its efficacy upon the precarious attention of the stokers? This may be done to some extent by self-acting apparatus; but whenever such has been fitted on board a steamer, it has been (so far as my experience goes) invariably abandoned after a few months' trial. It would appear, in fact, that the usual conditions of the stoke place of a sea-going steamer are incompatible alike with any great amount of discriminating attention to be expected from the men, or with the satisfactory working of a piece of nice mechanism left in their charge. There can, I think, be no objection to admitting a *small* and fixed quantity of air through a perforated plate behind the fire-bars (as shown in Williams's woodcut, Fig. 884), if this be done judiciously. The danger in such a case is, that the neighbouring plates may suffer harm from being one minute intensely heated as by the flame of a blow-pipe, and the next minute chilled by a cold blast after the flame has been expended, the continual expansion and contraction thus induced tending to weaken the plates by throwing iron-scale off their surface. It is therefore, perhaps, the safer plan to keep by the more usual expedient of admitting the air through a number of small holes punched in the fire-doors, say ⅜-in. holes at the distance of 1½ in. from centre to centre, which appears to answer every purpose, the door itself being slightly opened when more air is wanted. The bars must at the same time be kept covered with a *thin* fire, through which the air can penetrate, and not smothered with coals as shown in Mr. Williams's woodcuts.

"As to the alleged deficiency of absorbent power in the tube-surface of a marine boiler, there can be no question but that Mr. Williams's statements and conclusions demand the most careful and anxious consideration. I confess myself so far a convert to his views, that I would be glad to see the tubes curtailed in length to such an extent as to admit of a considerably larger space than is usually allowed between the ends of the bars and the tube-plate. That the first portion of the tubes should be so much more effective than the rest may, I think, be explained by supposing that the flame penetrates through them to this distance only, becoming then extinguished by the reduction of temperature in the tubes, in the same way that it cannot pass through the meshes of the wire gauze of the miner's lamp. That the remainder of the tubes should not absorb more heat from the gases in their transit, is certainly a very remarkable and unlooked-for result. The use of tubes of not less than about 3½ in. diameter seems preferable, as allowing the flame to penetrate further through them.

"While speaking of 'priming,' Mr. Williams remarks that my expression of a 'serious loss of heat being carried off by the water' is 'erroneous.' The extent of this loss is evidently just so much caloric as was necessary for raising the ejected water from the temperature of the feed to that of the water in the boiler.

"Lastly, with regard to superheated steam, it is now pretty well understood that with a temperature of from 280° to 300° Fahr. in the steam-pipes we have all the advantages of which the process is capable without endangering the valves and packings of the engines. I must differ from Mr. Williams, however, in thinking that its 'sole' advantage is the vaporization of the watery particles contained in the steam, as I think we derive an almost equal advantage from the saving of condensation in the pipes, ports, and cylinders."

Mr. C. Wye Williams, writing to the secretary respecting the above remarks of Mr. Murray, said:—"In reference to Mr. Murray's additional remarks, I have only to express my belief that his objections are severally and substantially answered in the extracts I have given from the report of Messrs. Armstrong, Richardson, and Longridge, on the proceedings at Newcastle (page 440). His remarks on the admission of air and 'smoke burning' seem to be the result of an oversight, on his part, as to what my plans and recommendations really are. My regret at this is the greater, as he has himself fully absolved me from the charge of suggesting speculative remedies, when he adds:—'I see no objection to admitting a small and fixed quantity of air through a perforated plate behind the fire-bars, as shown in Mr. Williams's woodcut, Fig. 884.' Again, Mr. Murray says:—'It is, perhaps, the safer plan to keep by the more usual expedient of admitting air through a number of small holes in the fire-doors, which appears to answer every purpose.' Had Mr. Murray looked further he would have found that this 'safer plan,' which 'answers every purpose,' is identically what I adopted under my patent of 1838, and was that exclusively used by me at the Newcastle experiments, which lasted twelve days, the claim of the patent being, 'The use, construction, and application of the perforated air-distributor, by which the atmospheric air is more immediately and intimately blended with the combustible gases generated in the furnace.'

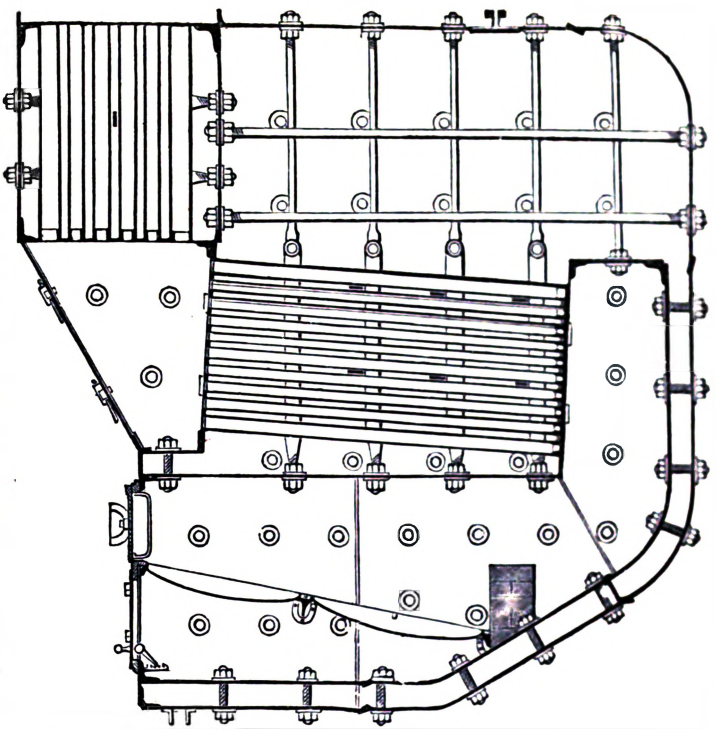
"As to the deficiency of the heat-transmitting power of tubes, which it was the main purpose of my paper to describe, Mr. Murray says all that was necessary in confirmation of my views, and in giving them the benefit of his concurrence, when he adds:—'As to the alleged deficiency of absorbing power in the tube-surface, there can be no question but that Mr. Williams's statements demand the most careful and anxious consideration. I confess myself so far a convert to his views that I would be glad to see the tubes contracted in length to such an extent as to admit of a considerably larger space than is usually allowed between the ends of the bars and the tube-plate.' If this be done, it will remove one of the impediments, both to the full combustion

of the furnace-gases, and the increased evaporative power of the boiler. On the whole, then, it appears that, so far from there being any essential difference between Mr. Murray and myself, we are substantially in accord on all essential points."

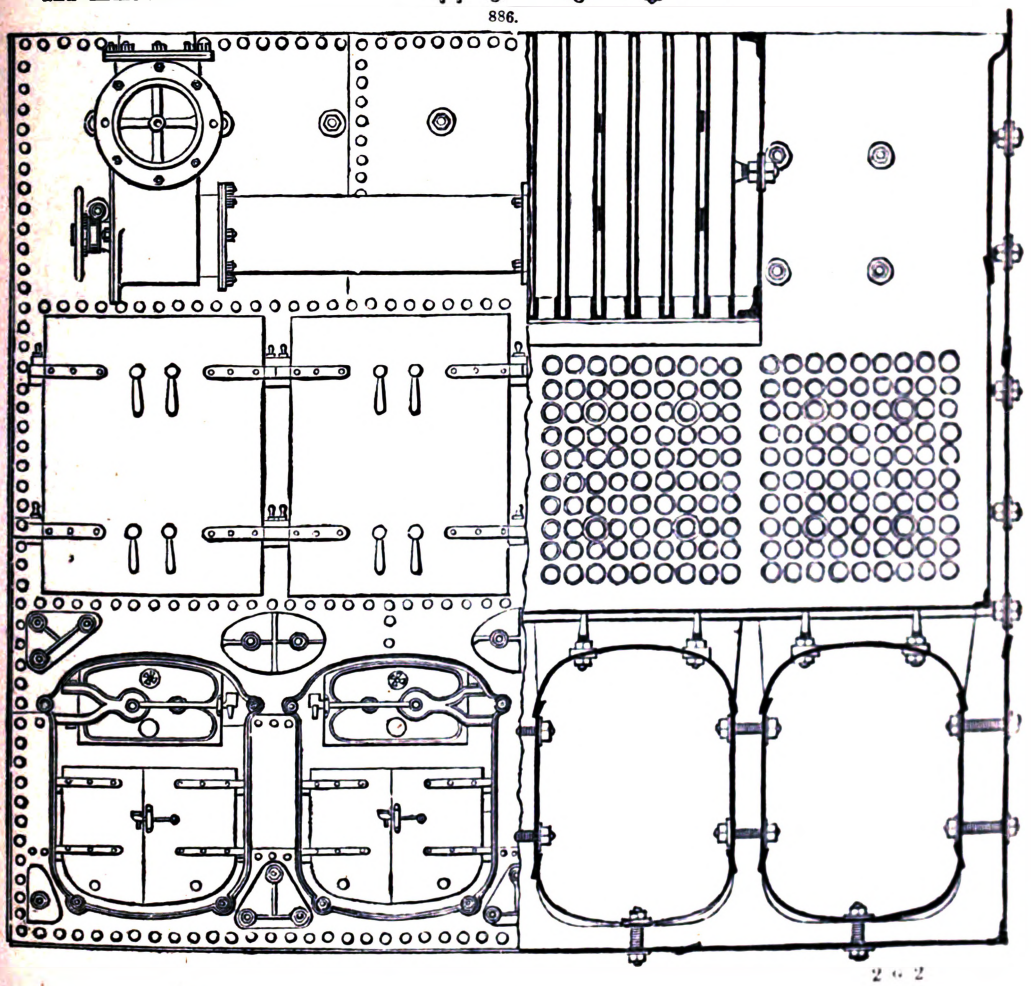
We now come to the present practice of engineers, by which different descriptions of boilers are constructed and arranged to suit various purposes. How far these numerous forms and combinations fulfil the necessary requirements, the engineer will, it is presumed, be able to decide, from the accurate experiments, abstract reasoning, and practical results which we have adduced.

*Marine Boilers.*—Fig. 885 shows an example of the high-type modern marine boiler, as designed by N. P. Burgh, and illustrated in his

885.



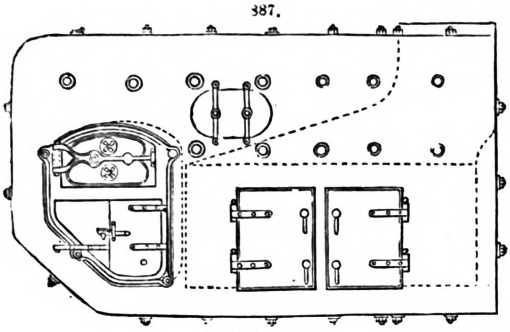
886.



practical work on Marine Engineering, to which we are indebted for many of our examples of marine boilers. The fire-box and combustion-chamber are partially separated by a brick bridge. The tubes have a slight rake inclining upwards at the smoke-box end, this end being the final evaporator. The vertical tubes in the upper portion of the smoke-box are for superheating. The fire-bars are inclined towards the inner extremities for two purposes, the one to assist the action of stoking or agitating the fire, and the other to accelerate the draught—it being remembered that the greater portion of the draught enters below the bars. Fig. 886 shows an enlarged front elevation of the same, half complete and half in section.

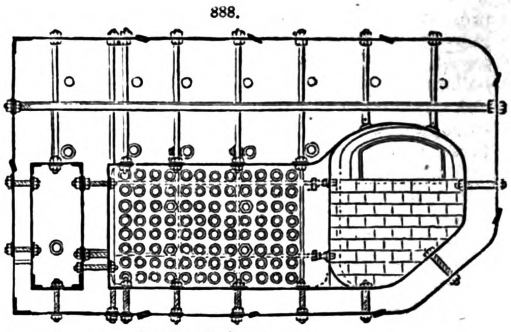
Figs. 887, 888, 889, show an end elevation, sectional plan, and sectional elevation of the boilers fitted in H.M.S.S. 'Vigilant,' 'Wanderer,' and 'Osprey,' by Maudslay, Sons, and Field. The disposition of the boilers in the hull is represented by the elevations, the plan referring to only one

887.



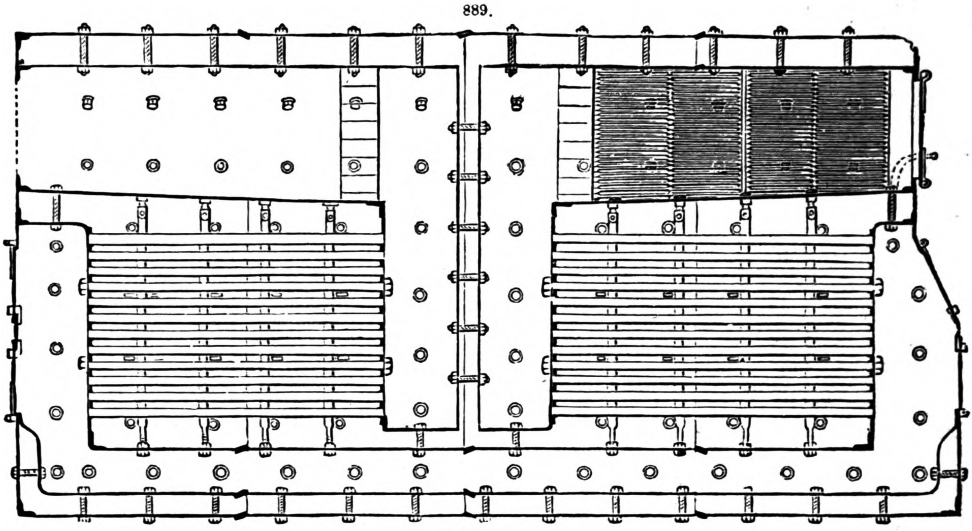
End elevation.

888.



Sectional elevation.

889.



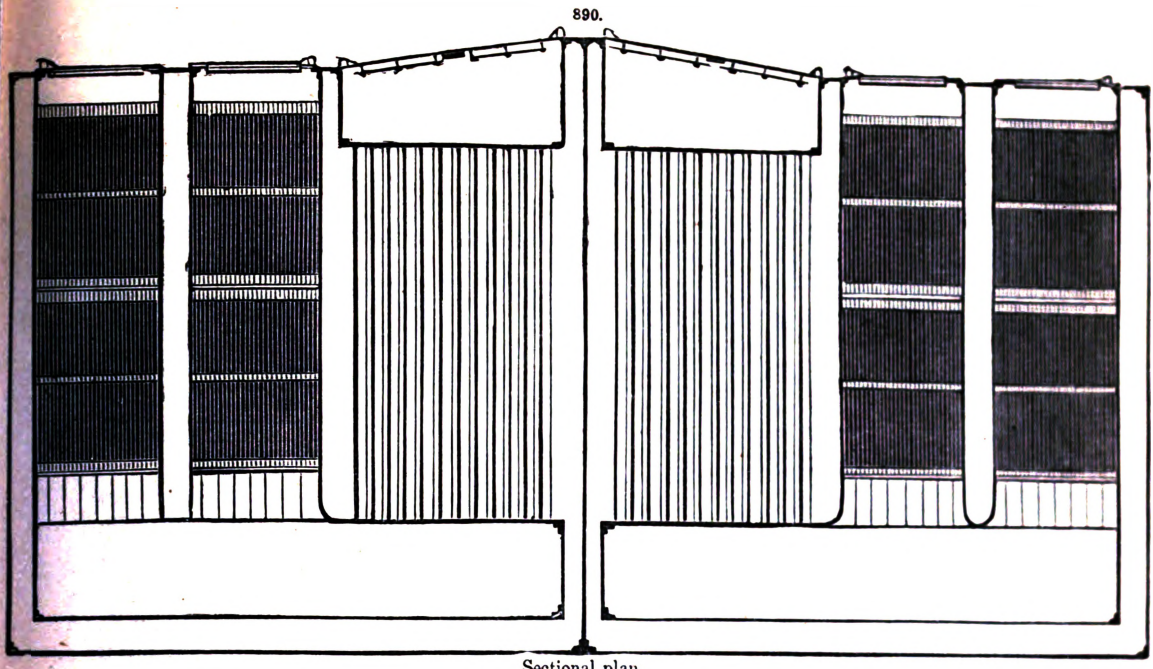
Sectional plan.

boiler. The fire-boxes are fore and aft of the shell at the side. The combustion-chambers, one to each grate, are at right angles with the fire-boxes; the tubes are arranged in a line with and outside each fire-box, thus forming a return action. A longitudinal flue is introduced, extending throughout the length of the boiler, so as to render the final uptake common to the smoke-boxes. On referring to the sectional elevation, it will be seen that this flue is the same height as the smoke-box, a divisional water-space causing a complete separation. The fire-box is contracted at the base-line, also the side and bottom of the shell are angularly connected. This form of construction is due to the beam of the hull for which the boilers were designed.

The details are:—Two boilers of 100 H.P. collectively; length of shell, 19 ft. 4 in.; width of one shell, 9 ft. 6 in.; height of shell, 5 ft. 10 in. There are four fire-grates, each grate being 6 ft. 4 in. long by 2 ft. 10 in. wide. The fire-box is 3 ft. 6 in. deep at each end. 192 of the tubes are 6 ft. 6 in., and 192 6 ft. in length. The total number of tubes is 384, each tube being 2½ in outside diameter.

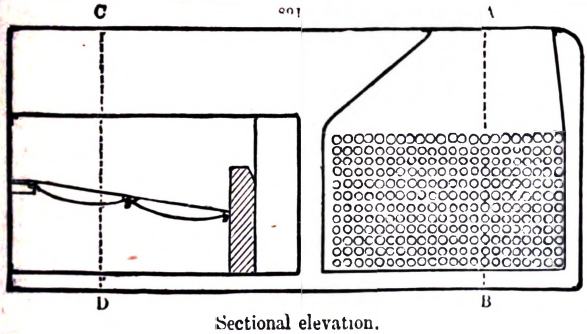
Fig. 890 represents a boiler with tubes, made by Maudslay, Sons, and Field, for H.M.S.S. 'Mutine' and 'Chameleon.' The boiler is of 66 H.P.; the shell is 9 ft. 8 in. long, 18 ft. 4 in. wide, and 7 ft. 6 in. high. There are four grates, each grate being 5 ft. 10 in. long by 2 ft. wide. The fire-box is 3 ft. 10 in. deep. Total number of tubes 262, each tube being 6 ft. long and 2½ in. outside diameter. There are two grates to each cluster of tubes, placed near the outer side of the shell. The combustion-chamber is at right angles with the grate. The tubes are placed in the centre between the fire-boxes. The smoke-boxes are at the boiler-front between the inner fire-boxes.

890.



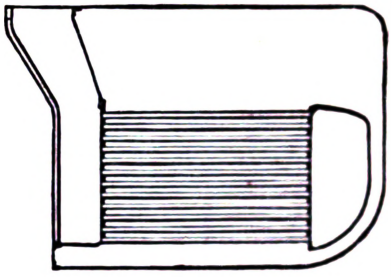
Sectional plan.

Figs. 891, 892, 893, 894, show elevation, plan, and sections of the two boilers of H.M.S.S. 'Reindeer' and 'Perseus,' by J. and G. Rennie. They are of 130 H.P. Length of shell, 16 ft.; width, 10 ft. 6 in.; height, 7 ft. 6 in.; six fire-grates, 5 ft. 6 in. long by 2 ft. 10 in. wide; fire-box, 4 ft. 6 in. deep; 528 tubes, each tube being 6 ft. long and 2½ in. outside diameter.



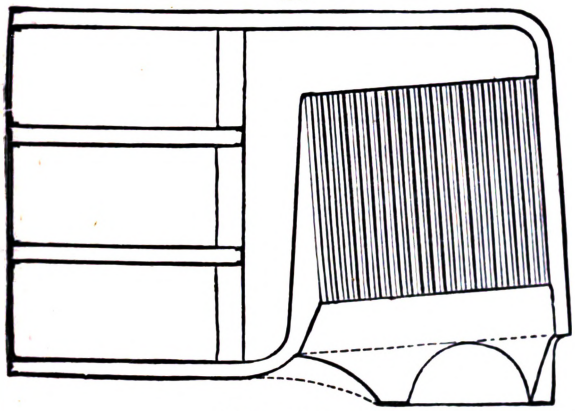

Sectional elevation.

892.



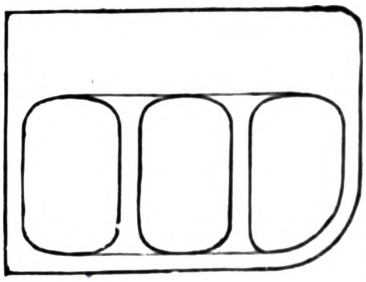
Section at A, B.

893.



Sectional plan.

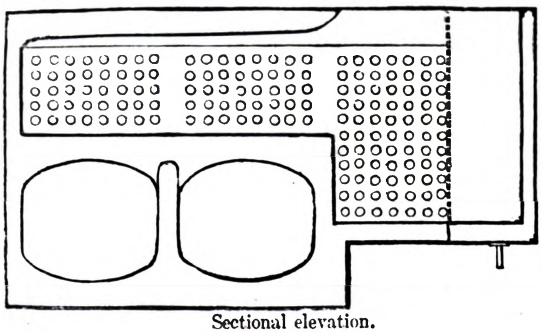
894.



Section at C, D.

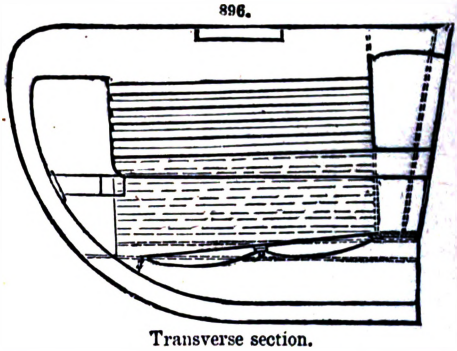
Figs. 895, 896, show elevation and section of the boilers made by J. and G. Rennie for S S.S. 'General Murillos' and 'General Victoria.' There are four boilers, of 200 H.P. collectively. Each shell is 12 ft. long, 10 ft. wide, and 7 ft. high. There are eight grates, each grate being 5 ft. 9 in. long by 3 ft. wide. The fire-box is 3 ft. deep in front, and 2 ft. at back. There are 628 tubes, 6 ft. long and 2½ in. outside diameter.

895.



Sectional elevation.

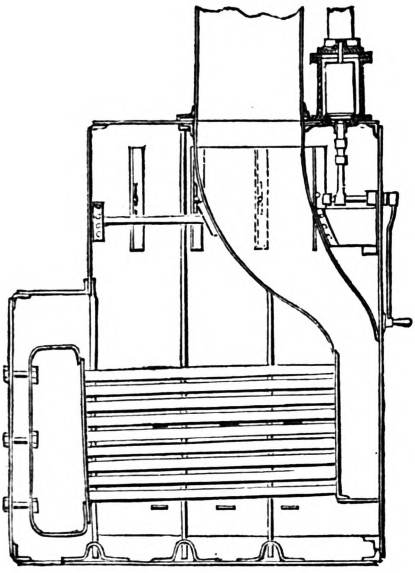
896.



Transverse section.

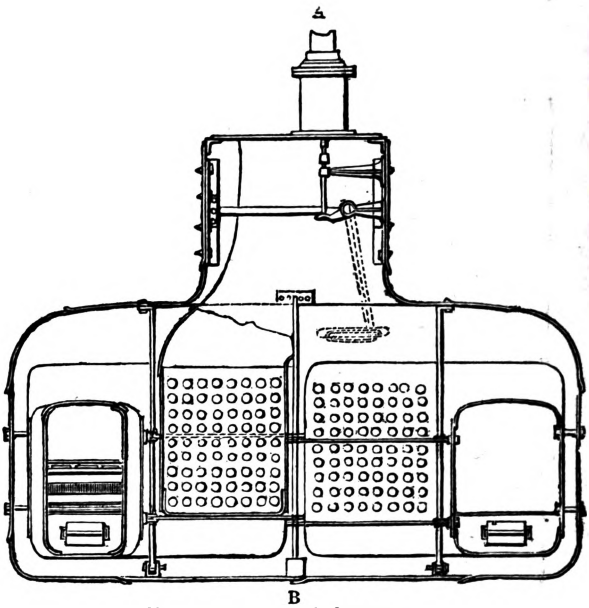
Figs. 897, 898, show the tubular boiler made by James Watt and Co. for the Bombay Steam Navigation Company. It is of 30 H.P. The shell is 7 ft. 1 in. long, 11 ft. wide, and 8 ft. 6 in. high. It has two grates, 4 ft. 9 in. long and 2 ft. 2 in. wide. The fire-box is 3 ft. deep. Number of tubes 144, each tube 4 ft. 11 in. long, 2½ in. outside diameter. The doors seen under the grate at the back, Fig. 898, are for the admission of air beyond the bridge, a suitable framework being fitted in the fire-box. The gear shown by the dotted lines and in the dome relates to the safety-valve. Fig. 897 shows the combustion-chamber, smoke-box, and uptake, in section. It will be seen that the tubes connecting the combustion-chamber and smoke-box are at an incline; this is for the purpose of accelerating the draught. The uptake is curved and surrounded by the steam; this renders partial superheating attainable without extra detail or expense.

897.



Sectional elevation through A, B.

898.



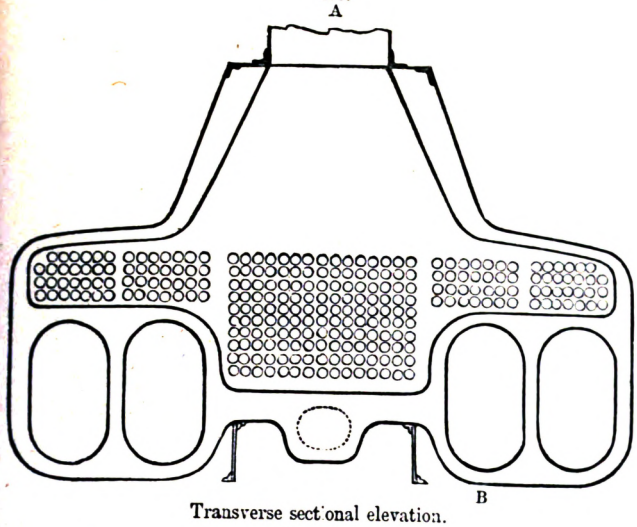

Transverse sectional elevation.

Figs. 899, 900, show the boilers made by James Watt and Co. for the S.S. 'Tyrsaad.' They are of 120 H.P. The shell is 8 ft. long, 15 ft. wide, and 10 ft. high. There are eight grates, 7 ft. long and 2 ft. wide. The fire-box is 3 ft. deep in front, and 3 ft. 3 in. deep at back. There are 520 tubes, each tube being 5 ft. 8 in. long and 2½ in. outside diameter.

Figs. 901, 902, 903, 904, represent the two boilers made by James Watt and Co. for H.M.S. 'Hornet.' They are of 100 H.P. Length of shell, 16 ft. 6 in.; width of one shell, 9 ft. 6 in.; height of shell, 7 ft. 6 in. Six grates, each grate 5 ft. 3 in. long by 2 ft. 4 in. wide. The fire-box is 3 ft. deep in front, and 3 ft. 6 in. at back. There are 440 tubes, each 5 ft. 6 in. long and 2½ in. outside diameter.

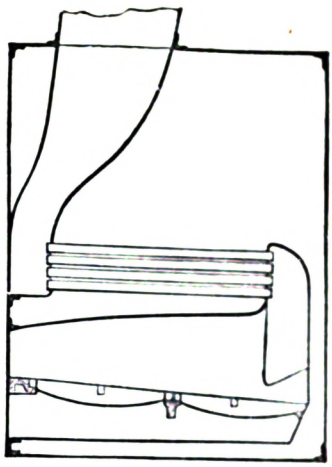
The tubular boiler invented by Edward N. Dickerson is shown in Fig. 905. It has two series of tubes, W and S, through one of which series the water passes, and upon the exterior of which

899.



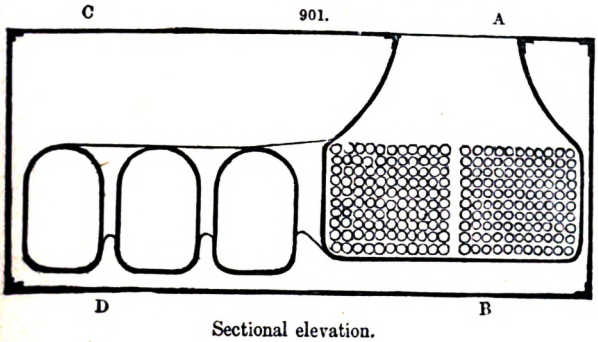

Transverse sectional elevation.

900.



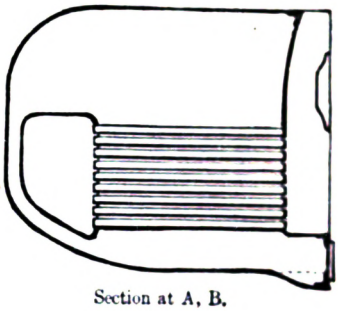
Section through A, B.

901.



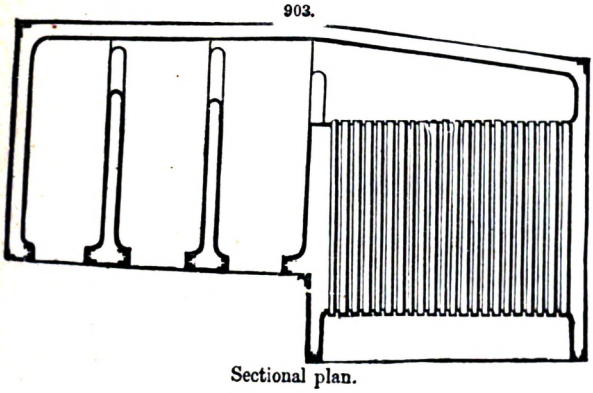

Sectional elevation.

902.



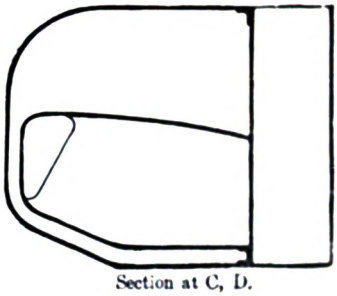
Section at A, B.

903.



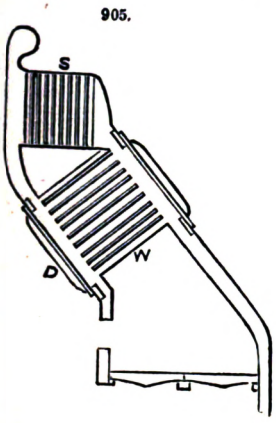
Sectional plan.

904.

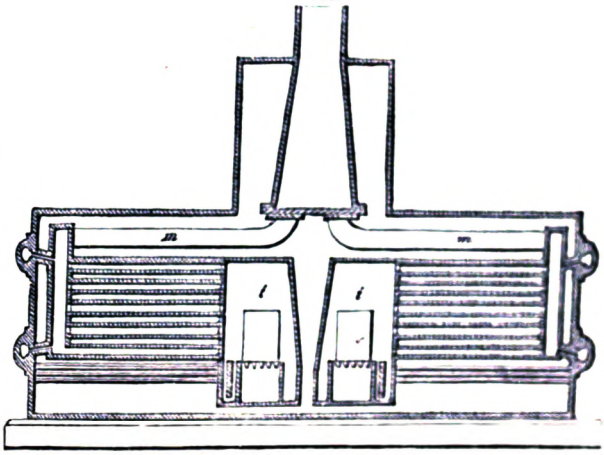


Section at C, D.

905.




906.

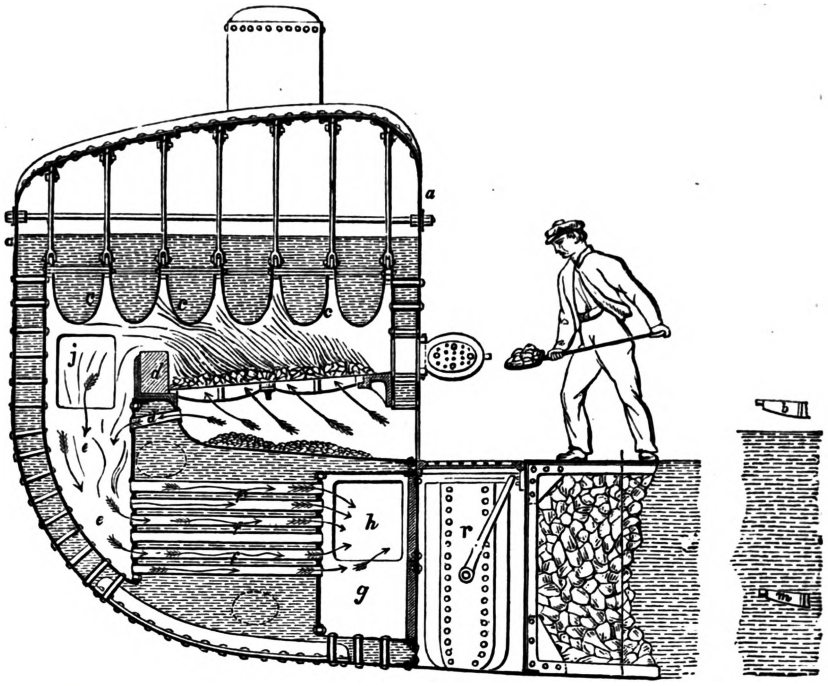


the heated products of combustion impinge, while the steam on its passage to the outlet is made to surround and envelop the other series through which the products of combustion are made to pass, thus superheating the steam. The water-tubes of this boiler are so arranged that by removing doors or plates D, both ends of the tubes may be reached and cleaned without going into the boiler.

Fig. 906 refers to the boiler invented by William Mont Storm. The boiler consists of a cylindrical horizontal shell, in the centre of which are situated two fire-boxes separated by a water-space. The smoke-boxes are situated within the water-space, with the pipes $m, m$ for circulating the smoke to the uptake. Flues are provided for conveying air to the furnace, which run parallel with the generating tubes; and a water-head is formed in each end of the boiler for affording access to the outer ends of the tubes. This water-head is connected with the boiler by circulating pipes, so that it is made to act as a generator of steam as well as a water-heater. The fire passes right and left through the flues or tubes to the chambers *i*, *i*, and thence through its proper conduit to the uptake.

Fig. 907 is an elevation in section of the marine steam-boiler of that ingenious inventor and engineer, Thomas Dunn. *a* is the outer shell of the boiler; *b*, the fire-grate, and *c*, the roof of the fire-box, which is formed of semi-elliptical plates riveted together at their edges, thereby producing a corrugated surface against which the products of combustion impinge; these corrugations give a larger heating-surface to the fire-box and increase its strength. Beyond the fire-grate *b* is the bridge *d*, over which the products of combustion pass to the down-flue *e*, then through the tubes *f*

907.

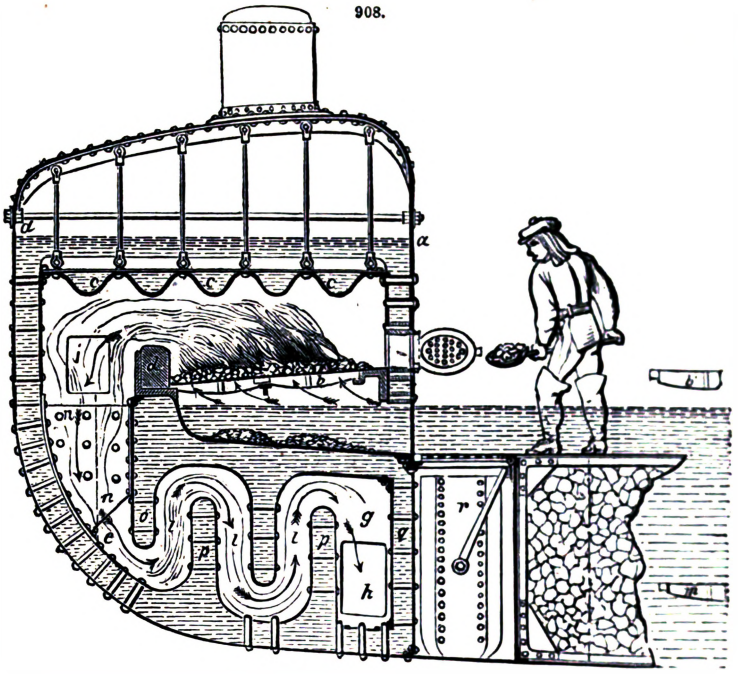



forming the multitubular part of the boiler, and then into the chamber *g* which communicates by means of the flue *h* with the chimney or funnel. Under the bridge *d* a few short tubes *d'* are inserted to admit air into the down-flue *e* for the purpose of igniting the inflammable gases passing over the bridge *d*. The flue *j* near the bridge is only opened when the fires are just ignited; but if, owing to the leaking of the vessel, the water should come in and close the lower flue *h*, the flue *j* may be opened so as to keep the engines going until the water rises in the vessel sufficiently to extinguish the fires. The grate-bar *m* is shown in about the position of the fire-grates in marine boilers of the ordinary construction, and the grate-bar *b* above it indicates the level of the fire-grate in Dunn's boiler.

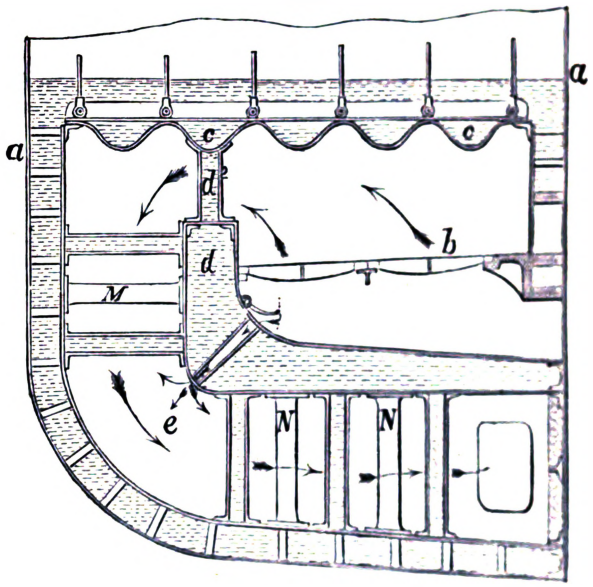
Fig. 908 is a section of another of Dunn's marine boilers. In this instance the roof of the fire-box is made of corrugated plates *c* stayed longitudinally and vertically, and the water-partitions *n*, shown in section in Fig. 909, are placed in the down-flue *e* to absorb a portion of the heat from the products of combustion in passing to the up and down flues *l*, which are formed by the water-partitions *o*, projecting downwards from the central portion of the boiler, and the partitions *p* projecting upwards from the lower part of the boiler. The chamber *g* and the flues *h* and *j* are similar to those above described in reference to Fig. 907. In this boiler the outer side of the chamber *g* is formed by the water-partition *q*, and consequently all the flues and lower portions of the boiler are perfectly water-tight, so that in case of the leaking of the vessel the boiler may be kept in full work until the water rises to the level of the fire-grate *b*. In both the marine boilers shown in Figs. 907, 908, the fire is applied near to the surface of the water, and in a most advantageous position for rapidly generating steam; the ashes and cinders are collected in the buckets *r*, and the direction of the products of combustion is indicated by the arrows.

Fig. 910 represents a modification of the marine boilers shown in Figs. 907, 908. In this boiler the heating-surface is increased, and the circulation promoted by the two sets of tubes M and N

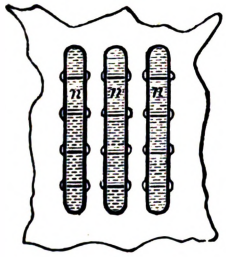
908.



910.



909.

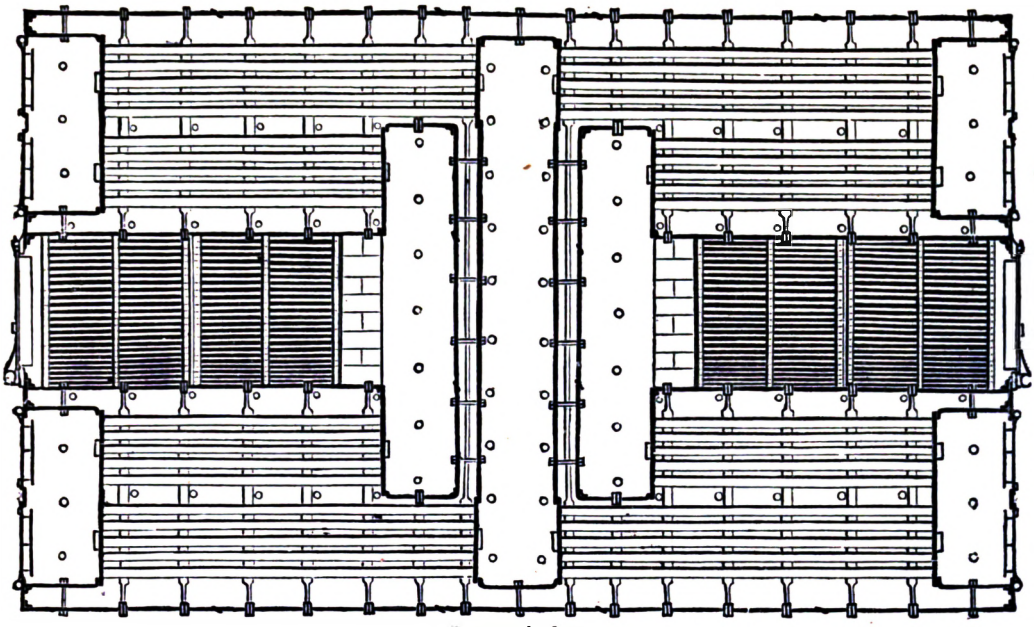


placed in the flue *e*. The bridge *d* is made to contain water, and it is connected to the corrugated roof *c* by pipes $d^2$.

Figs. 911, 912, show an elevation and plan of two boilers designed by N. P. Burgh for a gun-boat. They are of 100 H.P. collectively. The shell is 19 ft. 9 in. long, each shell 12 ft. wide and 5 ft. 9 in. high. There are four grates, 6 ft. long and 3 ft. wide. The fire-box is 3 ft. deep. There are 780 tubes, 400 being 5 ft. 9 in., and 380 7 ft. 6 in. long; outside diameter of each tube, 2½ in.

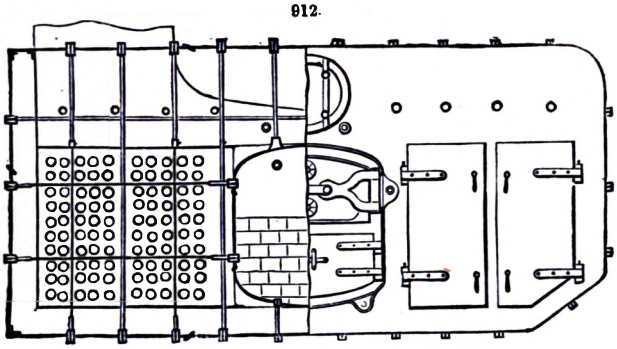
The boilers made by Maudslay, Sons, and Field, for H.M.S.S. 'Ajax' and 'Edinburgh,' are shown in plan, Fig. 913. In each ship there are two, of 450 H.P. collectively. The shell of each boiler is 34 ft. 6 in. long, 15 ft. 6 in. wide, and 9 ft. 10 in. high. There are twelve fire-grates, each grate 6 ft. 4 in. long and 3 ft. wide. The fire-box is 3 ft. 6 in. deep in front, and 4 ft. 2 in. at back. Number of tubes, 1506; each tube 4 ft. 10 in. long, 2½ in. external diameter.

911.



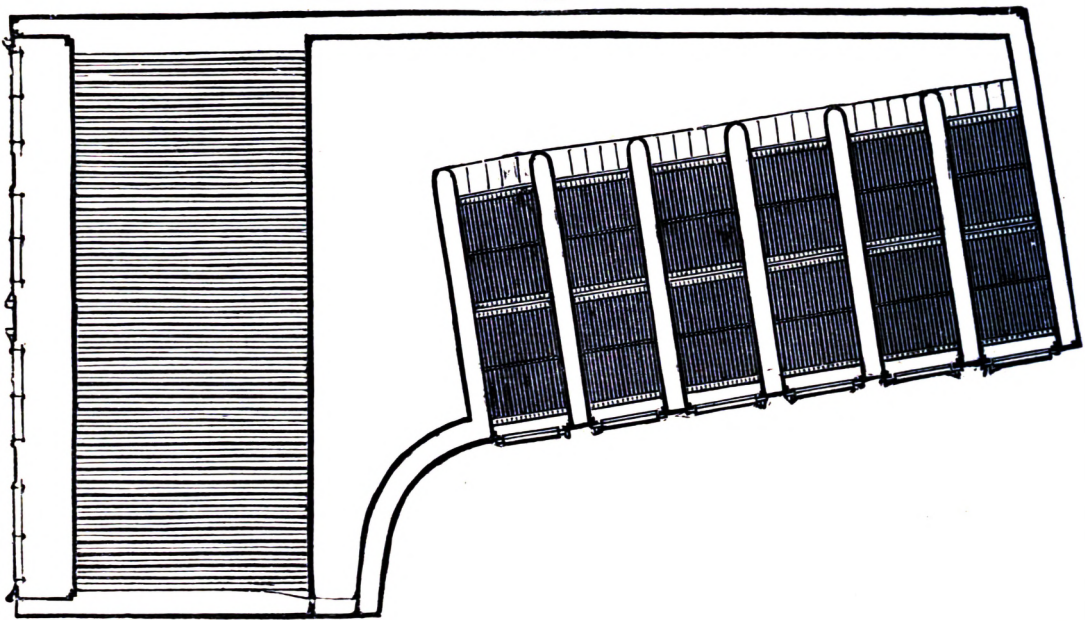
Sectional plan.

912.



Elevation, half in section, half complete.

913.



Figs. 914, 915, exhibit elevations of the boiler designed by N. P. Burgh for a steam yacht. It is of 25 H.P. The shell is 11 ft. 6 in. long, 7 ft. wide, 7 ft. high; one fire-grate, 6 ft. long, 2 ft. 9 in. wide; fire-box, 2 ft. 9 in. deep. Number of tubes, 72; each tube 8 ft. long and 2½ in. outside diameter.

E. Humphrys' marine boiler is shown, Figs. 916, 917. The uptake is constructed in such a manner that a number of vertical tubes may be placed in it, the uptake forming part of the main boiler. The vertical tubes serve as a superheating apparatus, and render unnecessary any pipes or valves for conducting the steam to the superheater.

Fig. 917 shows the tubes and smoke-box. Directly above the tubes a plate is fastened, and another plate is placed near the roof, the plates being connected by the vertical tubes and stays. The passage of the steam is indicated by the arrows.

The boilers represented in Figs. 918 to 921 are fitted in H.M.S. 'Oberon,' 260 H.P., and were designed by Capt. A. A. Cochrane and at Woolwich Factory respectively. The length of shell in Capt. Cochrane's boiler, Figs. 918, 919, is 12 ft.; width of shell, 11 ft. 6½ in.; number of steel tubes, 915; length of steel tubes, 3 ft. 3 in.; outside diameter of steel tubes, 1¾ in.; actual weight of boiler, 20 tons 7 cwt.; actual weight of water, 12 tons 8 cwt. 1 qr.

| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes | sq. ft. | 1310·54 | 10·08 | 18·25 |
| „ „ furnaces, &c. | „ | 337·83 | 2·6 | 4·71 |
| Total heating-surface | „ | 1648·37 | 12·68 | 22·96 |
| Area of fire-grate | „ | 71·79 | ·55 | .. |
| Capacity of combustion-chamber | cub. ft. | 157·2 | 1·21 | 2·19 |
| Area at throat of „ | sq. in. | 2146·37 | 16·51 | 30·0 |
| „ between close tubes | „ | 1942·0 | 15·0 | 27·04 |
| „ under trap or water-space | „ | 2099·5 | 16·15 | 29·2 |
| „ between smoke-box door and water-space | „ | 1799·0 | 13·83 | 25·05 |
| „ at mouth of uptake | „ | 1728·0 | 13·3 | 24·0 |

Capacity of boiler, 1460·5 cub. ft.; capacity for water, 444·78 cub. ft.; capacity for steam, 315 6 cub. ft.

The length and width of shell of the boiler made at Woolwich Factory, Figs. 920, 921, are the same as that shown in Figs. 918, 919. The height of the boiler is 12 ft. 2½ in.; number of brass tubes, 394; length of brass tubes, 6 ft. 6 in.; outside diameter of brass tubes, 2½ in.; actual weight of boiler, 21 tons 13 cwt. 8 lbs.; actual weight of water, 14 tons 19 cwt. 3 qrs.

| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes | sq. ft. | 1674·5 | 12·88 | 22·08 |
| „ „ furnaces, &c. | „ | 234·0 | 1·8 | 3·08 |
| Total heating-surface | „ | 1908·5 | 14·68 | 25·16 |
| Area of fire-grate | „ | 75·81 | ·58 | .. |
| Capacity of combustion-chamber | cub. ft. | 55·18 | ·42 | ·727 |
| Area at throat of „ | sq. in. | 2144·0 | 16·5 | 28·3 |
| „ through tubes | „ | 1564·18 | 12·03 | 20·63 |
| „ at mouth of uptake | „ | 1728·0 | 13·3 | 22·8 |

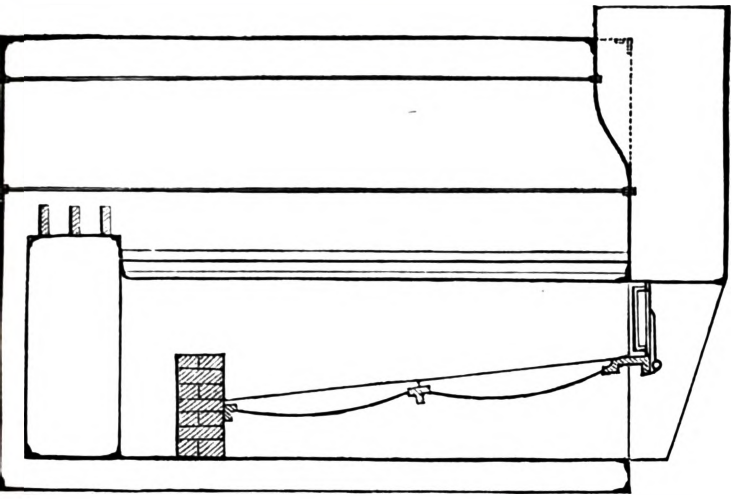
Capacity of boiler, 1460·5 cub. ft.; capacity for water, 537 cub ft.; capacity for steam, 369 cub. ft.

The boilers for H.M.S. 'Audacious,' 800 H.P., are made on two plans, one by Ravenhill, Hodgson, and Co., and the other by Capt. A. A. Cochrance. Figs. 922, 923, 924, show the boiler by Ravenhill, Hodgson, and Co. The number of tubes is 409; length of tubes, 6 ft. 7 in.; outside diameter of tubes, 3 in.; estimated weight of boiler, 22 tons 5 cwt.; estimated weight of water, 14 tons 5 cwt. 2 qrs.

| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes | sq. ft. | 2208·6 | 16·56 | 25·175 |
| „ „ furnaces, &c. | „ | 304·78 | 2·28 | 3·47 |
| Total heating-surface | „ | 2573·38 | 18·85 | 28·65 |
| Area of fire-grate | „ | 87·725 | ·65 | .. |
| Capacity of combustion-chamber | cub. ft. | 105·43 | ·8 | 1·2 |
| Area at throat of „ | sq. in. | 3560·0 | 26·7 | 40·58 |
| „ through tubes | „ | 2429·0 | 18·22 | 27·69 |
| „ at mouth of uptake | „ | 1980·0 | 14·85 | 22 57 |

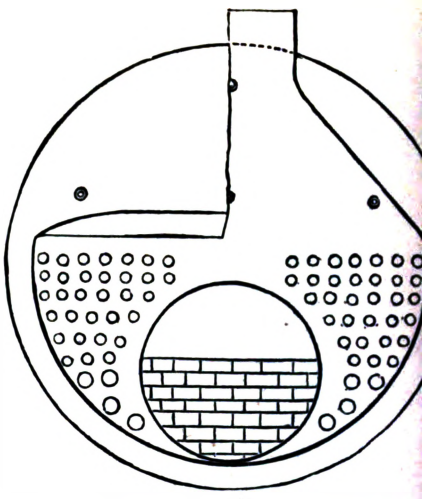
Capacity of boiler, 1898 cub. ft.; capacity for water, 519·68 cub. ft.; capacity for steam, 483 25 cub. ft.

914.



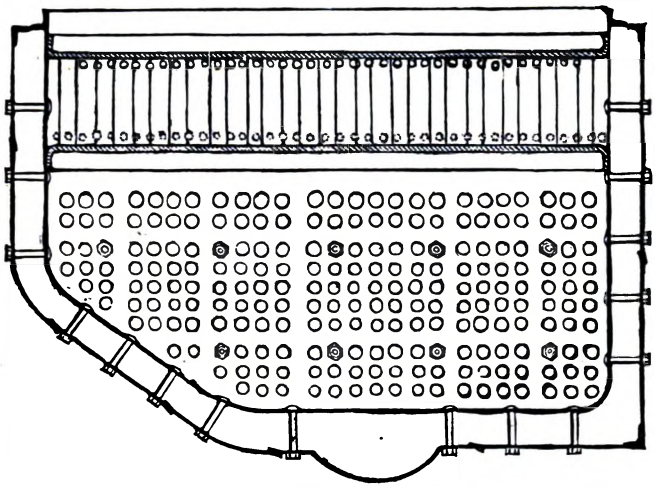
Longitudinal sectional elevation.

915.



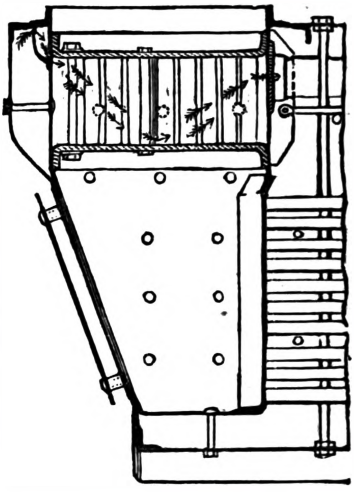
Transverse sectional elevation.

916.



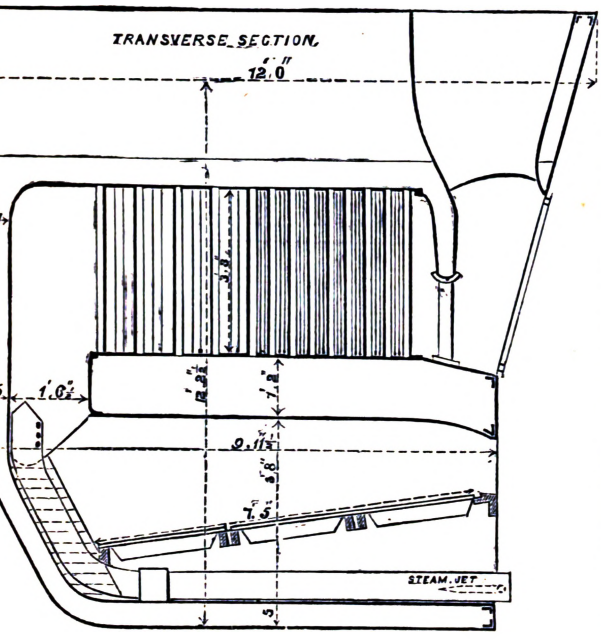
Sectional elevation.

917.

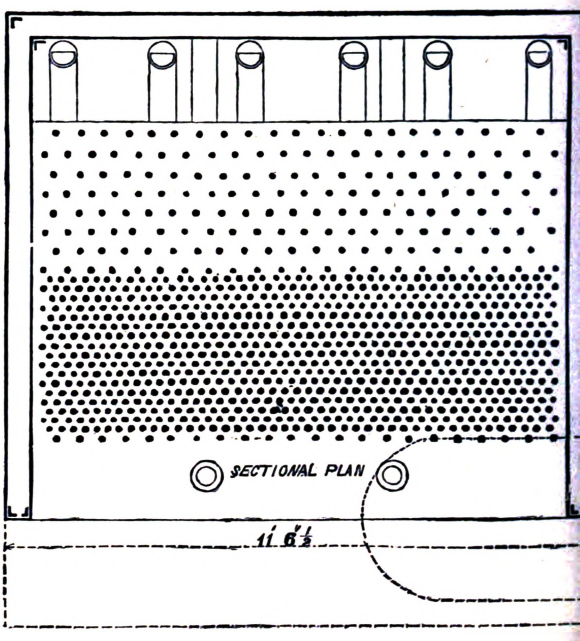


Transverse section.

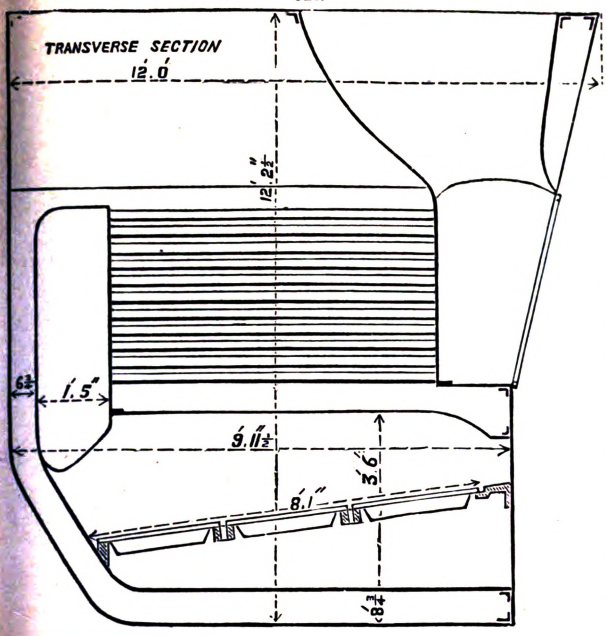
918.



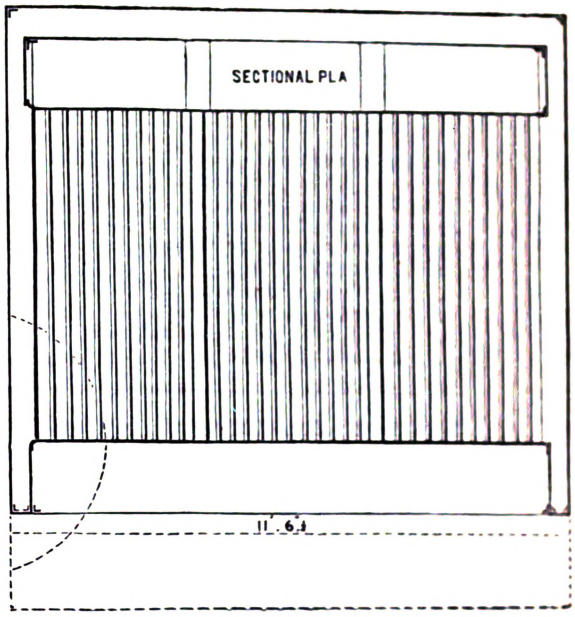

919.



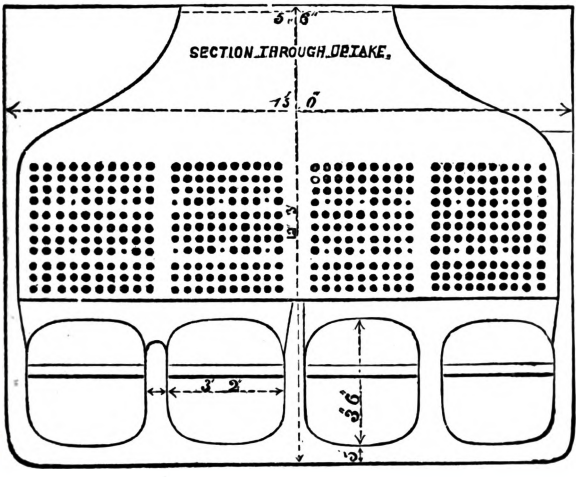
920.



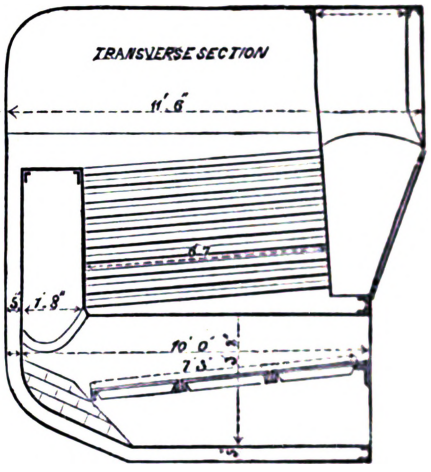

921.



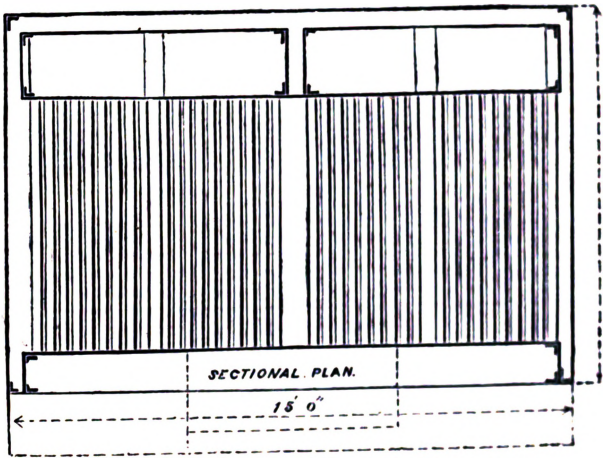

922.




923.




924.

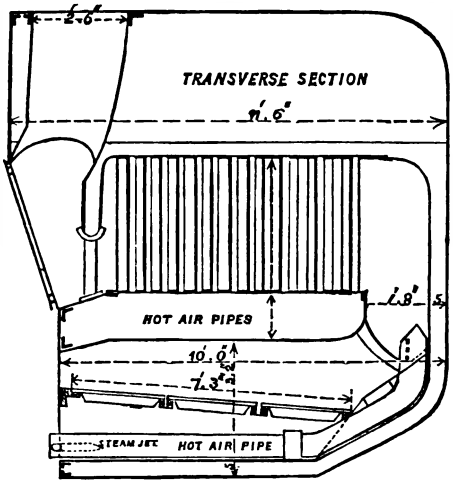


Figs. 925, 926, 927, exhibit Capt. Cochrane's plan. The particulars are:—Number of steel tubes, 870; length of steel tubes, 3 ft. 6 in.; outside diameter of steel tubes, $1\frac{3}{4}$ in.; estimated weight of boiler, 24 tons 2 qrs.; estimated weight of water, 12 tons 8 cwt. 2 qrs.

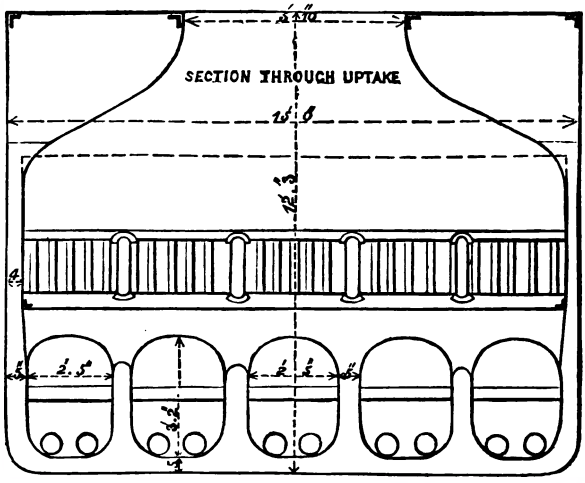
| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes .. .. .. .. .. | sq. ft. | 1395·44 | 10·5 | 15·9 |
| „ „ furnaces, &c. .. .. .. | „ | 513·19 | 3·84 | 5·85 |
| Total heating-surface .. .. .. .. .. | „ | 1908·63 | 14·34 | 21·75 |
| Area of fire-grate .. .. .. .. .. .. | „ | 87·725 | ·65 | .. |
| Capacity of combustion-chamber .. .. .. | cub. ft. | 282·0 | 2·1 | 3·21 |
| Area at throat of „ .. .. .. | sq. in. | 2905·0 | 21·7 | 33·11 |
| „ between close tubes .. .. .. .. | „ | 3192·0 | 23·2 | 36·4 |
| „ under trap or water-space .. .. .. | „ | 2728·0 | 20·4 | 31·1 |
| „ between smoke-box door and water-space | „ | 2898·0 | 21 7 | 33·0 |
| „ at mouth of uptake .. .. .. .. .. | „ | 2016·0 | 15·2 | 22·98 |

Capacity of boiler, 1898 cub. ft.; capacity for water, 445·3 cub. ft.; capacity for steam, 483·25 cub. ft.

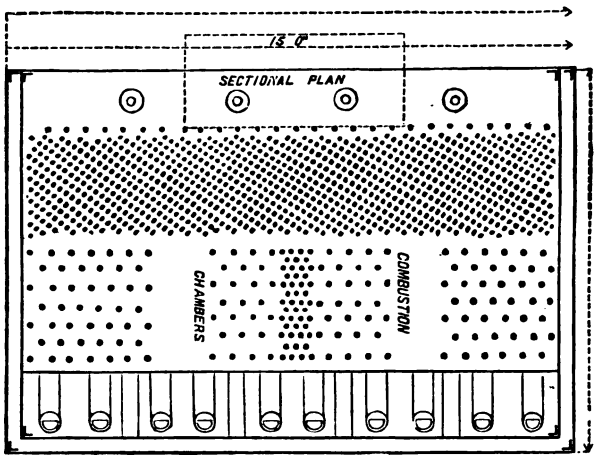
925.




926.




927

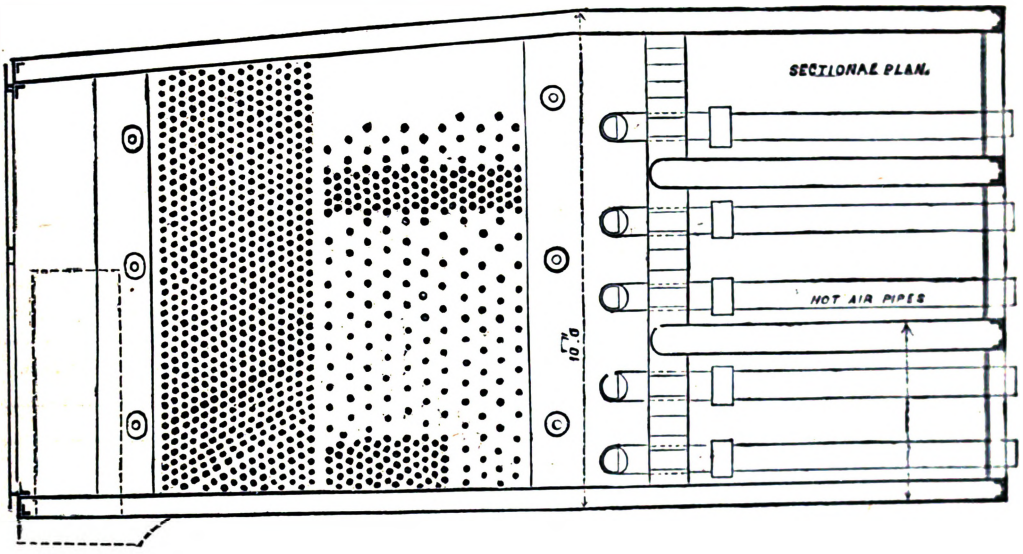


H.M.S. 'Chanticleer,' 200 H.P., is fitted with boilers designed by Capt. Cochrane and by the Government Factory at Woolwich respectively. Figs. 928, 929, 930, represent those by Capt. Cochrane. Number of steel tubes, 929; length of steel tubes, 2 ft. 6 in.; outside diameter of steel tubes, 1¼ in.; actual weight of boiler, 18 tons 18 cwt. 2 qrs. 18 lbs.; actual weight of water, 8 tons 11 cwt. 22 lbs.

| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes .. .. | sq. ft. | 758·6 | 10·53 | 15·6 |
| „ „ furnaces, &c. | „ | 241·89 | 3·35 | 5·0 |
| Total heating-surface .. .. .. | „ | 1000·49 | 13·88 | 20·6 |
| Area of fire-grate .. .. .. .. | „ | 48·37 | ·67 | .. |
| Capacity of combustion-chamber | cub. ft. | 158·7 | 2·204 | 3·2 |
| Area at throat of „ | sq. in. | 2160·0 | 30·0 | 44·66 |
| „ between close tubes .. .. | „ | 1545·0 | 21·45 | 32·15 |
| „ under trap or water-space .. | „ | 1486·0 | 20·64 | 30·72 |
| „ at mouth of uptake .. .. | „ | 1053·0 | 14·62 | 21·77 |

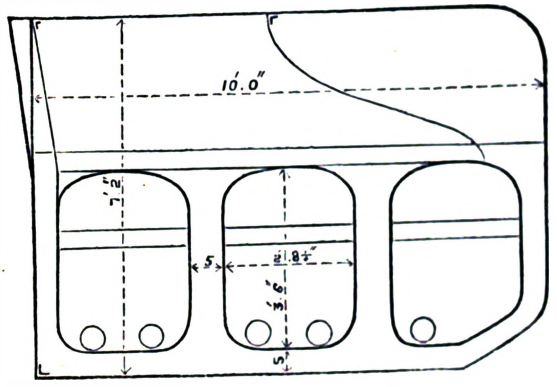
Capacity of boiler, 1384·87 cub. ft.; capacity for water, 306 7 cub. ft.; capacity for steam, 454·5 cub. ft.

928.

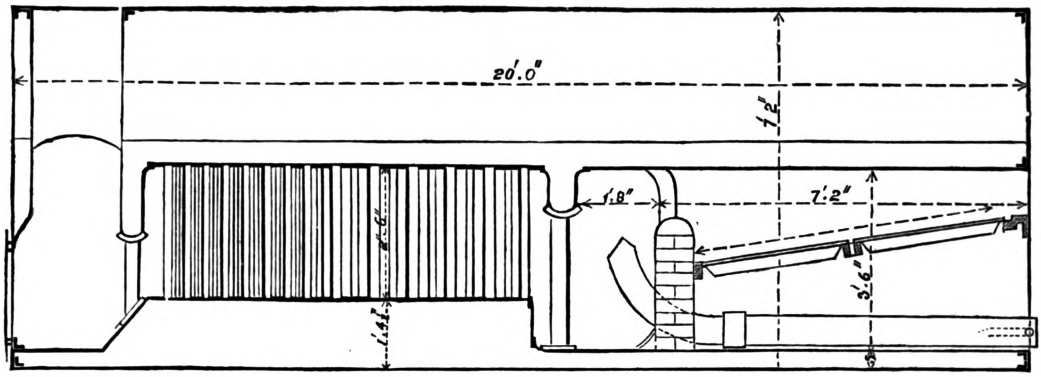



929.

TRANSVERSE SECTION



930.

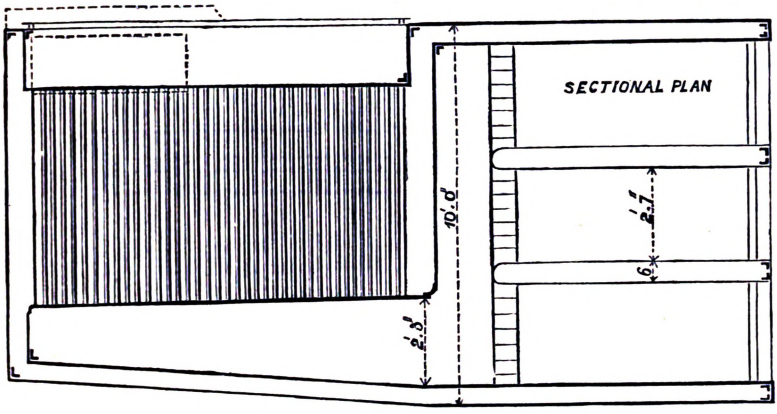



Figs. 931, 932, 933, show the Woolwich Factory boilers. The number of brass tubes, 337; length of brass tubes, 5 ft. 6 in ; outside diameter of brass tubes, 2½ in.; actual weight of boiler, 19 tons 2 cwt. 3 qrs. 8 lbs.; actual weight of water, 11 tons 3 qrs. 7 lbs.

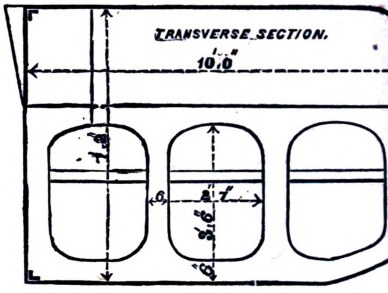
| | | Total. | Each nominal H.P. | To each foot of Grate. |
|---|---|---|---|---|
| Heating-surface in tubes .. .. | sq. ft. | 1213·2 | 16·84 | 26·08 |
| „ „ furnaces, &c. | „ | 176·39 | 2·45 | 3·8 |
| Total heating-surface .. .. .. | „ | 1389·59 | 19·29 | 29·88 |
| Area of fire-grate .. .. .. .. | „ | 46·51 | ·646 | .. |
| Capacity of combustion-chamber | cub. ft. | 121·84 | 1·69 | 2·62 |
| Area at throat of „ | sq. in. | 1075·0 | 14·93 | 23·11 |
| „ through tubes .. .. .. | „ | 1337·8 | 18·58 | 28·78 |
| „ at mouth of uptake .. .. | „ | 888·0 | 12·33 | 19·1 |

Capacity of boiler, 1384·87 cub. ft.; capacity for water, 395·7 cub. ft.; capacity for steam, 454·5 cub. ft.

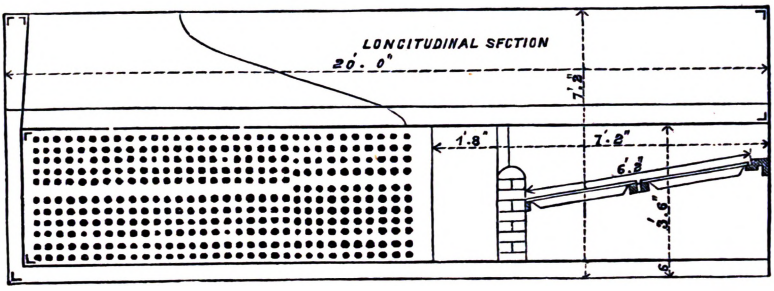
931.




932.

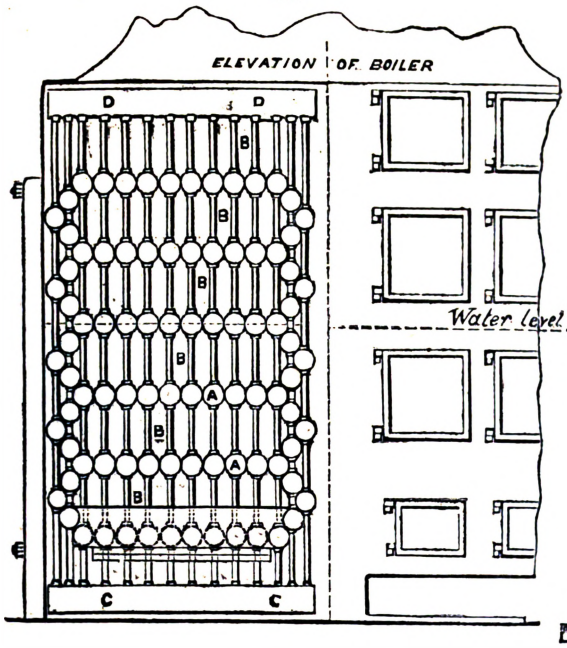



933

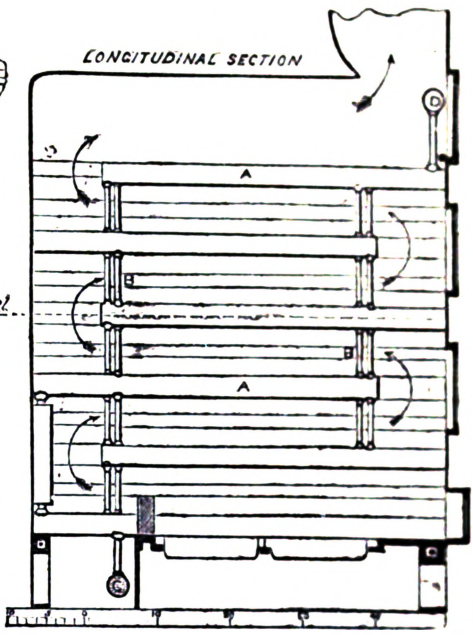


*Stationary Boilers.*—The boiler shown in Figs. 934, 935, was designed by A. W. Williamson and L. Perkins for very high pressure steam with great expansion. It supplies steam to an engine of 60 H.P., which works at a pressure of 500 lbs. to the square inch.

934.




935.




The boiler consists of a number of horizontal straight wrought-iron tubes A, welded at the ends, and connected with one another by smaller vertical pipes B. These tubes contain the water to be evaporated, and the steam, whilst the fire is outside them. It is essential that the larger tubes be horizontal or nearly so, and that each of them be connected to the next tube by means of two of the connecting-pipes. The boiler contains five layers of the larger tubes of 2¼ in. internal and 3 in. external diameter; the connecting-pipes are ¾ in. internal and 1¼ in. external diameter. In working, the water-level is in the middle layer of tubes, as shown by the dotted line in Figs. 934, 935; it remains free from the violent undulations which occur frequently in boilers where the internal space is not divided off. It is probable that a circulation establishes itself in the water, which rises with the bubbles of steam through the vertical connecting-pipe at one end of the tube, and descends by itself through that at the other. The gases from the fire pass backwards and forwards between the layers of tubes, as shown by the arrows in Fig. 935, and remain long enough in contact with them to allow of a very good absorption of the heat. In another similar boiler used for some time, there were eight layers of tubes above the fire. The boiler is thus made up of a number of vertical subdivisions arranged side by side, each containing five to eight parallel tubes. The several sections are all connected together at the bottom, by means of a cross tube C, with connecting-pipes to each section, through which the water finds the same level in all the sections. The steam is taken off through a similar cross tube D at the top of the boiler, with a connecting-pipe to the highest tube of each section. All the sections are proved with water pressure up to 3000 lbs. the square inch.

The boiler has about 12 sq. ft. of grate-surface, but the total area of the air-spaces between the bars does not amount to more than is supplied by 6 sq. ft. of ordinary grate-surface; and accordingly the fire is large but slack. The total heating-surface amounts to 882 sq. ft. The capacity is about 40 cub. ft., half of which is water-space and half steam-room. The whole boiler is firmly held together by cast-iron girders, and encased in non-conducting sides and top made of four thicknesses of light plate riveted together and kept about ¾ in. apart by ferrules, so as to form three closed air-chambers. This arrangement is specially adapted for marine boilers.

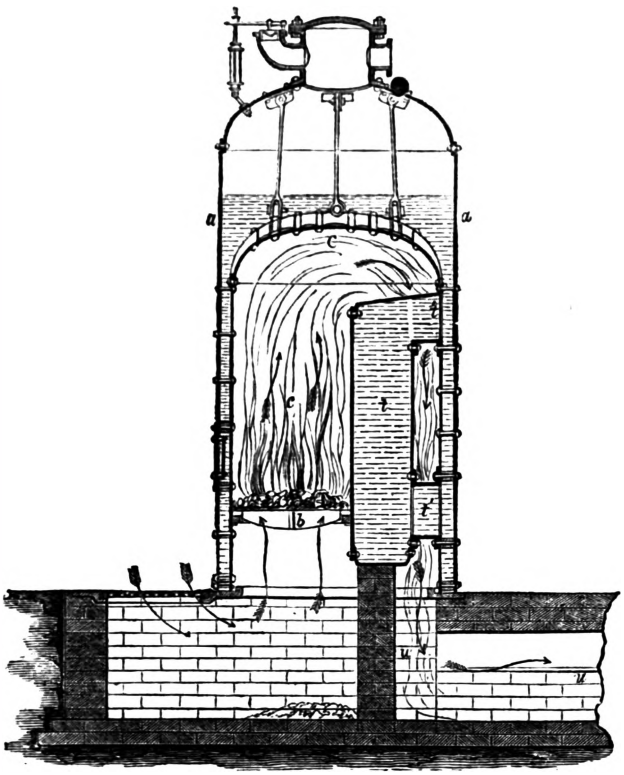
The flue from the boiler is made to pass through a box containing the three cylinders of the engine, passing first down the small or high-pressure cylinder, then up the middle one, and finally acting on the low-pressure cylinder. The temperature of the gases in this box varies from 400° to 500° Fahr. After leaving the box, they pass downwards through a vertical square flue 10 ft. long, giving up their remaining heat to the feed-water which is forced up through a wrought-iron coil of ¼-in. pipe contained in the flue, having 200 sq. ft. of heating-surface. At the bottom of this flue the gases enter a vertical iron funnel of 40 ft. height and 24 in. diameter. The heat is so completely abstracted by the feed-water coil, that after leaving it the gases have never been found hotter than 100° Fahr.

This small quantity of heat in the chimney gave sufficient draught to cause the evaporation of 8½ cub. ft. of water an hour in the boiler; but by the aid of a small fan, driven by a belt from the main shaft of the engine, the evaporation was usually kept at 15 cub. ft. an hour. The evaporating power of the boiler was tested by means of a water-meter, and in an experiment of 5 hours' duration 390 lbs. of anthracite coal evaporated 420 galls. of water, which is about 10¾ lbs. of

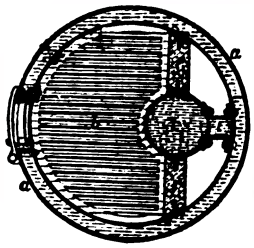
water the lb. of coal. There is no doubt that a larger boiler with small proportionate loss of heat by radiation to the outer air would give a still more favourable result.

Fig. 936 is an elevation, and Fig. 937 a plan, both in section, of Thomas Dunn's vertical boiler.

936.




937.




*a* is the shell, *b* the grate, *c* the fire-box; *t* is a large pipe which is kept full of water, the communication between the water-space surrounding the fire-box being effected by the branch pipes *t'*: to the outside of the tube *t*, and to the inside of the fire-box, are riveted T or angle irons, to hold in position the fire-clay or other slabs *t'*, shown in Fig. 937; these slabs and the tube *t* form the partition to separate the up-draught from the down-draught; and the fire-clay of the slabs when red-hot ignites the smoke, and consumes it before it arrives at the flue *u* communicating with the chimney.

Dunn's vertical boiler with two fire-grates is shown in Figs. 938, 939. *a* is the shell, *b b* the grates, *c* the fire-box, divided in the centre by the two water-partitions W, W, the space between which forms the down-flue. The upper end of the partitions W, W, is partially closed by a perforated fire-clay top W', the object of which is to ignite the inflammable gases, and to prevent the passage of smoke into the down-draught flue. At the bottom of the down-flue are placed the pipes V, through which the feed-water passes, and is thus partially heated in passing to the boiler.

Figs. 940 to 944 illustrate a very novel and useful arrangement, introduced by Hawksley, Wild, and Co., of Sheffield. It consists in building a furnace for puddling, heating iron and steel or other material, inside the boiler-flue, thereby utilizing the waste heat.

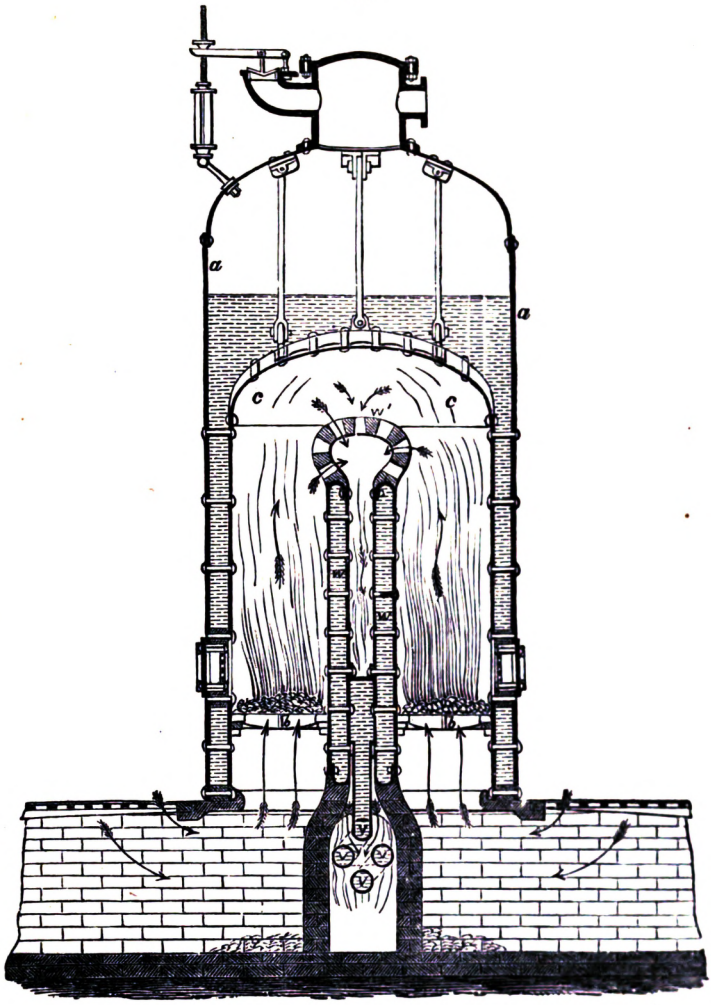
A is the steam-dome; B, furnace-door, the doors are placed on both sides of the furnace, so that it can be worked as a right or left hand furnace, or, in case of long forgings, right through; C, firing-hole door; D, fire-brick lining of furnace; E, furnace-bed; F, slag-bridge; G, tapping-hole for furnace-slag; H, heat-retainer for furnace-neck; I, circulating water-tubes; K, flange arrangement, for expansion, contraction, strengthening, reducing flue, and retaining the heat.

Robert Daglish and Co.'s multitubular boiler is shown in Figs. 945, 946, 947. A, A, is the stop-valve with safety-valve, B steam-dome, C manway and cover, D chimney and damper, E steam-gauge, F water-gauge and gauge-cocks, G feed-valve and pipes, ' mud-hole for clearing out.

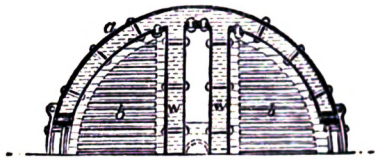
Samuel Smart and Co.'s vertical syphon water-tube boiler, shown in Figs. 948, 949, is of simple construction, consisting of a cylindrical shell with internal cylindrical fire-box, from the crown of which the water-tubes are suspended, hanging free into the fire. Every part of the boiler is easy of access for the purpose of cleaning; and as no strain is thrown upon any part by expansion or contraction, the tubes being fixed at one end only, the boiler is less liable than many other kinds to get out of order, and a great source of expense, in the shape of repairs, is thereby avoided.

Into each of the water-tubes a syphon is inserted, which extends down into the water-space of the boiler a short distance beyond the ends of the tubes. These syphons act as circulating tubes when the boiler is at work, supplying the water-tubes constantly with water from the water-

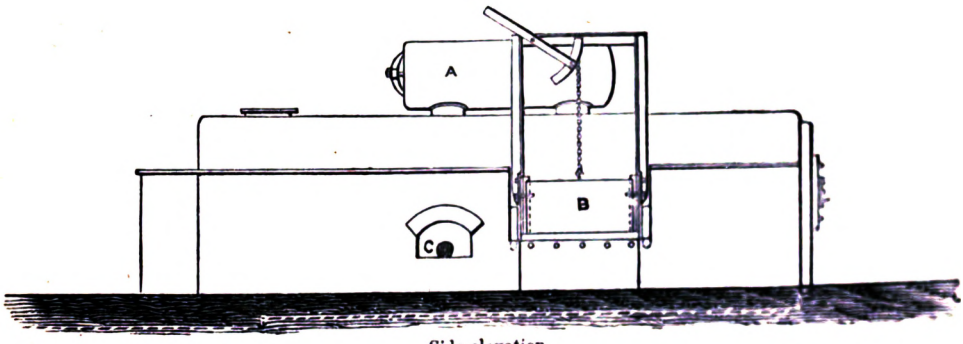
938.




939.

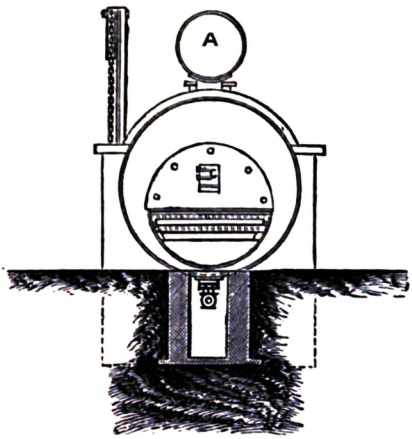



940.



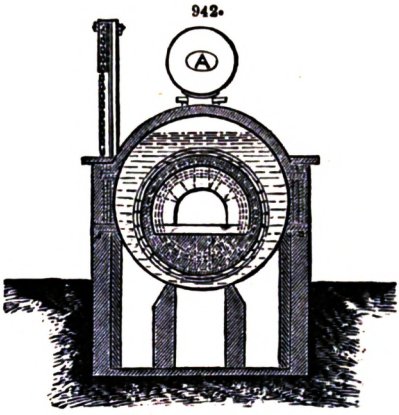

Side elevation.

941.



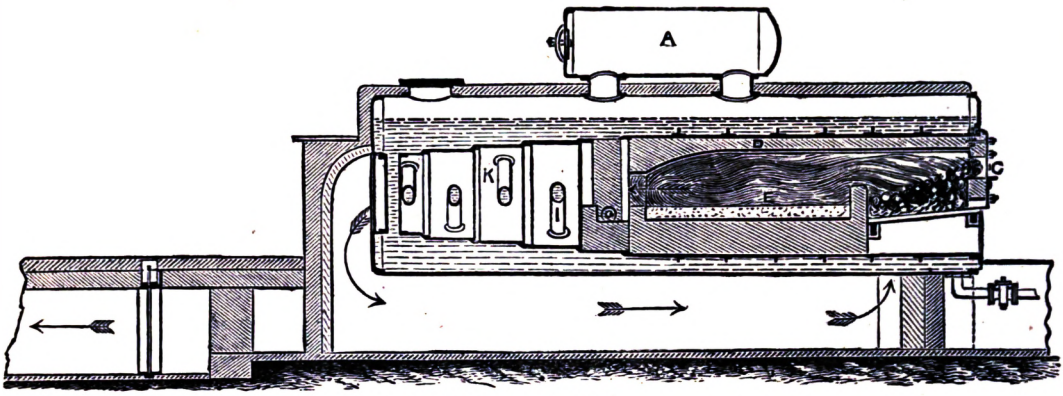

End elevation.

942.



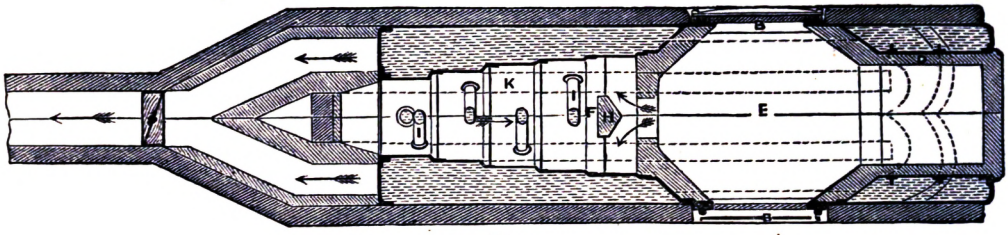

Transverse section.

943.




Longitudinal section.

944.

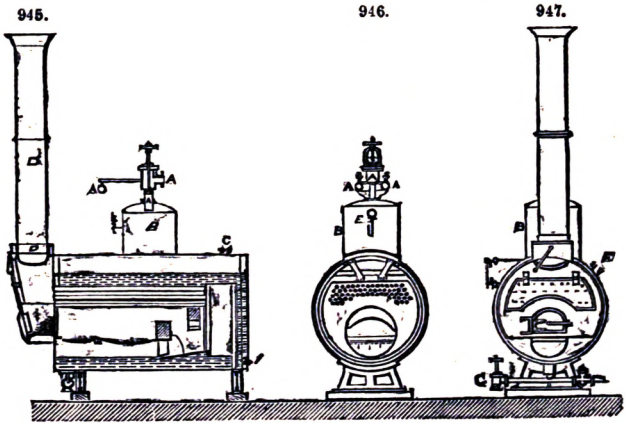



Plan.

945.

946.

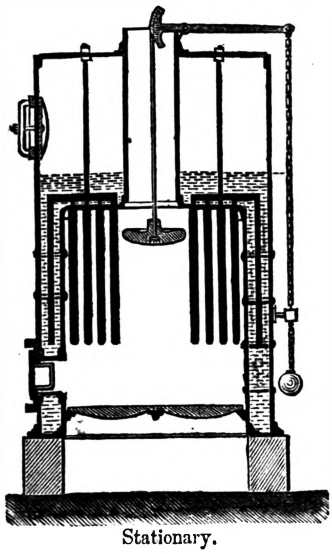
947.



casing, where it has a tendency to keep cooler than in the upper part of the boiler, but by means of the circulation through the syphons the temperature is equalized.

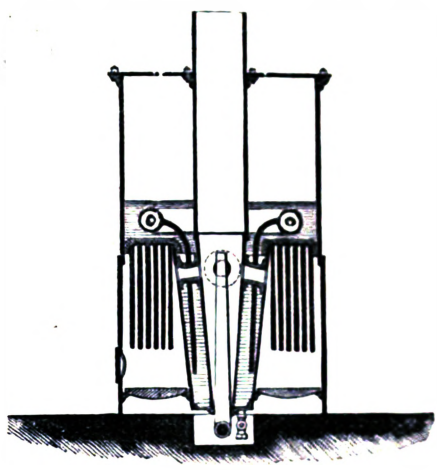
The tubes used under ordinary circumstances, in stationary and marine boilers, are of an external diameter of $1\frac{3}{4}$ in. and $2\frac{1}{2}$ in., with the exception of the portable boilers, in which smaller tubes are used.

948.



Stationary.

949.



Portable.

In the portable boiler, Fig. 949, the water-space surrounding the fire-box is omitted for the sake of lightness, and the hanging tubes are simply enclosed in a sheet-iron casing which carries the fire-grate. The central flue is carried down below the grate, and a water-space of the shape of an inverted cone is constructed around this flue, with short lateral flues for the escape of the smoke. Into this water-space the ends of the syphon tubes are taken, and the action will be precisely as in the stationary boiler already described. The blow-off cock is situated at the bottom of the conical water-space, and into the bottom opening of the flue the exhaust-pipe of the engine is fitted so as to close the opening, the nozzle of the exhaust-pipe terminating just above the lateral smoke-flues, and the exhaust steam is by this arrangement made to produce a powerful blast. In cases where even this central cone adds too much to the weight of the boiler it is dispensed with, and the circulation and blowing out is provided for by means of a peculiar arrangement of two-way cocks, and the boiler is made without any water-casing at all.

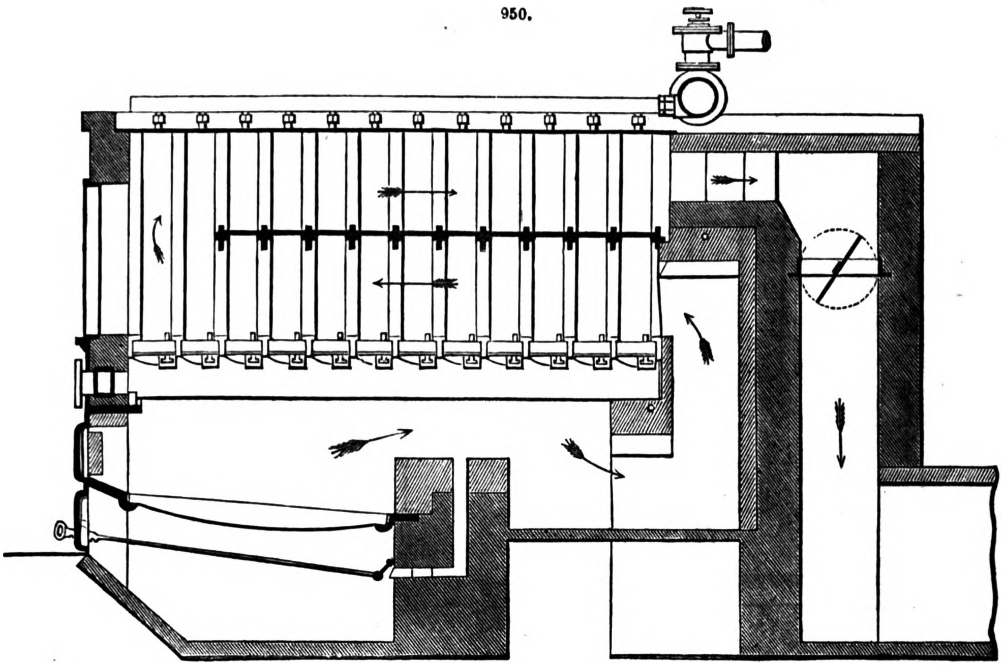
By using very small tubes in these boilers, a large amount of heating-surface can be put into a very small space; and as the boiler contains only a small quantity of water, which is made to circulate very rapidly over a large surface in very thin streams, steam is generated in a few minutes, and with a good blast in the chimney a quantity of steam is supplied for any length of time.

Howard's boiler, Figs. 950, 951, 952, 953, consists of a series of vertical tubes, 4 ft. 6 in. long and 7 in. in diameter, of wrought iron, welded, and closed at the upper end by flat plates less than half an inch thick welded in. Round the lower end of these tubes a heavy ring of cast iron with two projecting lugs is fixed. The tube is roughened at the lower end for a length of about 4 in., it is then placed in a mould and the metal cast about it. There results so perfect a union that the tube and the pipe are virtually rendered one. The tubes are disposed in transverse rows in a flue intervening between the furnace proper and the chimney. The lower ends of all the tubes in a transverse row are united by a cast-iron tube about 10 in. in diameter outside, and of considerable thickness. This tube is further strengthened by transverse perforated partitions. It will be seen that on the upper side of each cast-iron tube, flat pieces, or pedestals, are cast. In each of these is turned an annular groove as wide as the end of the vertical tube is thick, say $\frac{1}{2}$ in., and of considerable depth. The ends of the vertical tubes project slightly beyond their cast-iron base rings, and this projection fits into the circular channel before referred to. The end of the tube is turned off in the lathe.

In two opposite corners of the squares or pedestals on the cast-iron tube, recesses are made, and into each of these is slipped a heavy gun-metal tapped nut. These nuts can be drawn out or put in laterally, but they are held down by the cast iron of the pedestal which overhangs them on three sides. The base rings of the vertical tubes have lugs cast on them, which, when the tube is put in place, correspond with the gun-metal nuts to which they and the tube with them are secured by two bolts, one on each side, screwed into the nuts. Before the tube is put in place, a ring of composition, made of lead and tin, is dropped into the annular groove, and on this the end of the tube rests; and being forced down by the two bolts at opposite sides, makes a joint tight at any pressure which the tubes can sustain, and yet one which may be made and broken ten times in the day if necessary.

Each tube has within it an internal one, similar to that introduced by Ogle, rising up through the water-space, dividing the water into annular and central columns. The current of heated

950.



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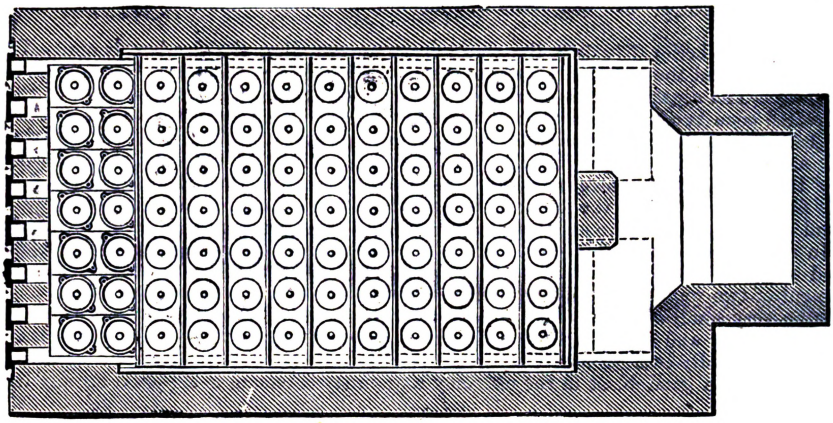

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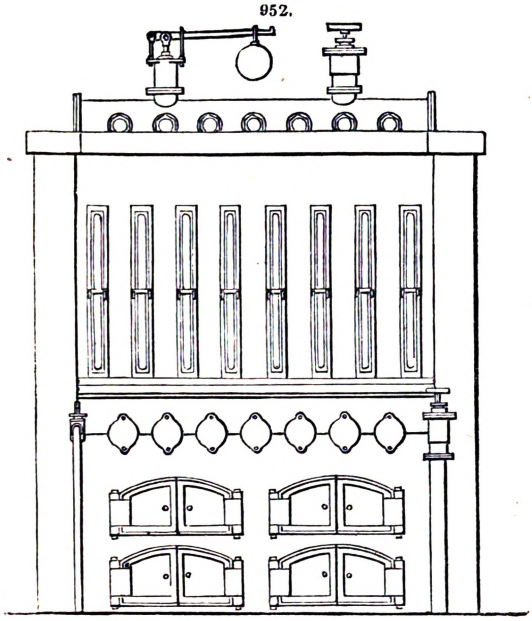

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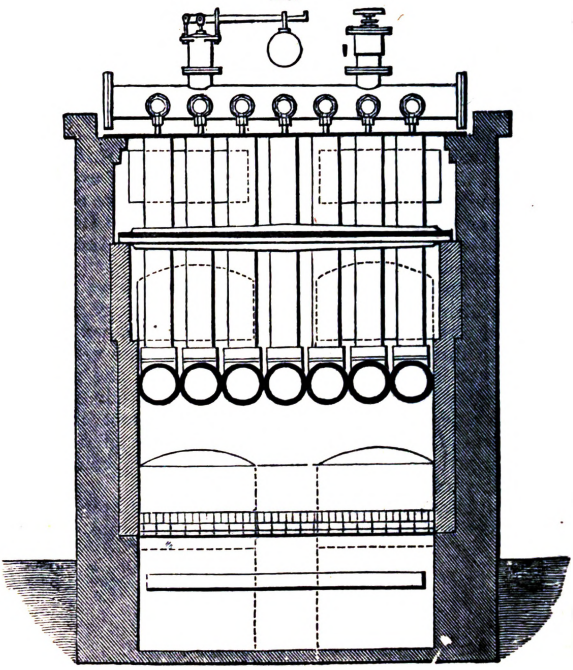


gases impinging upon the tubes, causes the water in the outer spaces to rise to the top and flow down to the bottom of the inner tubes; in consequence, a most active circulation is kept up in every part of the boiler.

From the upper ends of the tubes a short piece of welded gas-pipe rises. This pipe serves to carry off the steam to the main steam-pipe. Between every double row of generating tubes one steam-pipe is fixed horizontally, and the short tubes are bent over by an easy curve and screwed on to the sides of these secondary steam-pipes. All the secondary pipes open into one large pipe running at right angles to them. On this is fixed the safety-valve, and to a flange at one end the steam-pipe to the engine, or, where more boilers than one are used, a branch of that pipe is fixed. The effect of this arrangement is that the generating tubes are only secured at one end, and can, therefore, expand or contract as they like without imposing any strain on any part of the boiler. The steam-pipes are also free to move as they wish, the curve in the small pipes from the generating tube providing sufficient elasticity to meet any demands which are likely to be made on them. The cast-iron bottom mains can expand and contract as they please, and in any direction.

The manner in which the feed-water is introduced will be easily comprehended. Each transverse main has its own supply-pipe.

The furnace consists of the fire-chamber proper, which contains the grate, covered by a heavy brick-arch. In front of this is the tube-chamber, answering very much to the hearth of a puddling furnace; and under this last the flues are returned before going to the chimney. It is one of the distinguishing principles of this boiler, that no joint of any kind is exposed to the action of the fire, or heated products of combustion, while they retain a temperature much above that of the steam within the boiler. In order to carry out this object, the tiers of vertical tubes are set as follows:—The transverse cast-iron mains rest on side walls, and a central wall which establishes a wheel draught; the mains are fixed rather closely together, and, as soon as they are put in place, cast-iron plates are laid between them on flanges or ribs cast on the sides of the mains for the purpose; on these are laid bricks and fire-clay to such a height as to cover the junctions of the tubes with the mains effectually; the lower half of the mains project into the under-flues and absorb the last dregs of heat from the gases on their flight to the chimney. On the upper ends of the tubes wrought or cast iron plates are also laid, and these are covered with six or eight inches of sand to keep in the heat. By taking off the sand and removing a couple of plates, access may always be had to the interior of the tube-chamber. It will be remarked that the whole tube, steam-space and all, being exposed to the heat, its upper portion would be liable to rapid destruction. To prevent this a provision apparently insignificant, but really very important, is introduced, in the shape of certain screens of fire-clay, which extend across the tube-chamber and protect the upper portions of the tubes from the impact of the flame.

954.

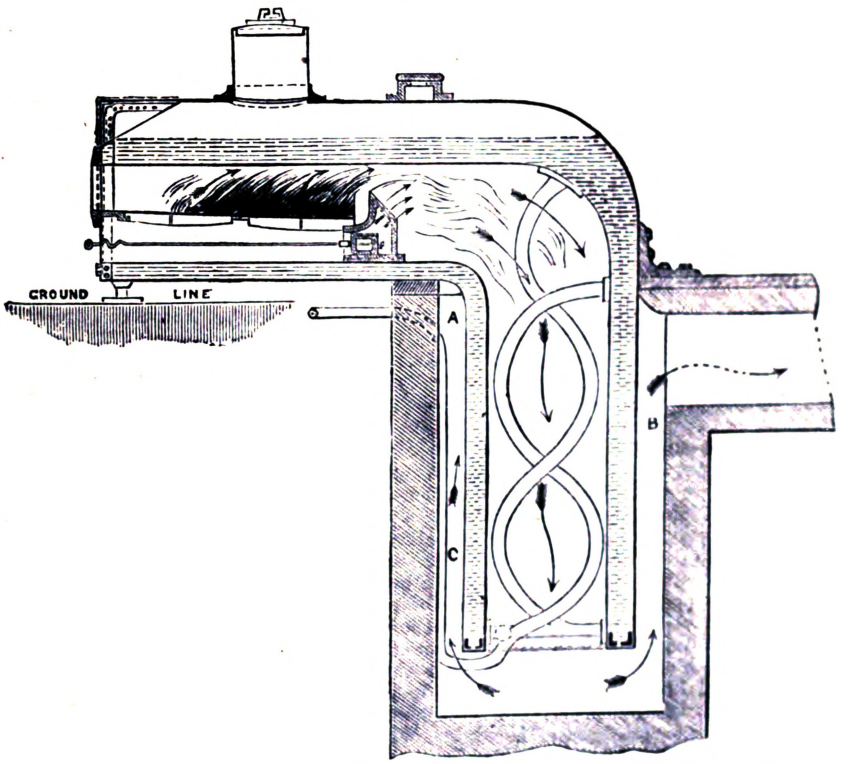
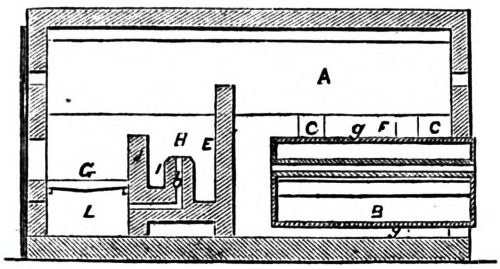



Fig. 954 is a longitudinal section of one of Thomas Dunn's boilers. The lower portion of this boiler is at right angles to the upper portion, and is contained in a chamber or pit of fire-brick; the products of combustion on leaving the flue surround the lower part of the boiler, A, B, C, and

escape to the chimney by the flue B. In this boiler the fire-brick bridge rests upon a hollow perforated cast-iron chamber, within which is a sliding wedge block; this block is now shown open to admit air behind the bridge, and it can be closed from the front of the boiler by the handle and rod shown in the figure. The pipes for heating the feed-water are placed in the flue; and as these pipes are connected to the upper and lower sides of the flue, there will be a constant circulation in the feed-water pipes.

Charles T. Boardman's arrangement for a boiler consists of two cylindrical boilers A A, Figs. 955, 956, placed side by side, and one inclined tubular boiler B, arranged below the near portions of the

955.

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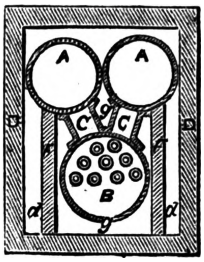
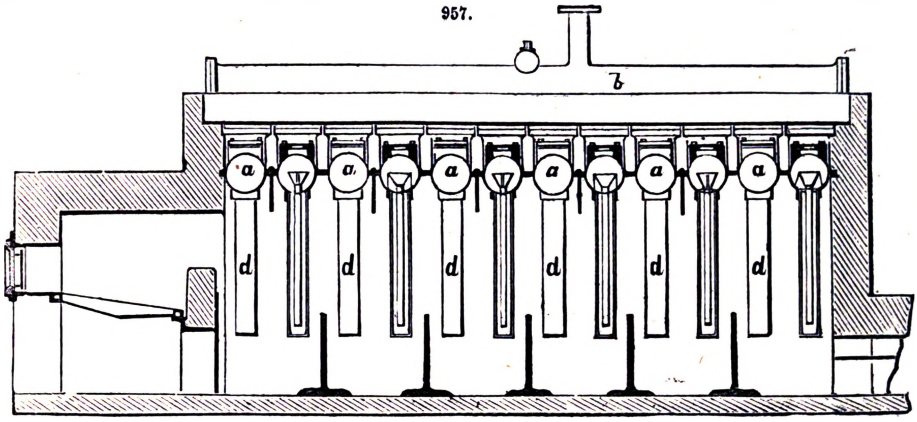



cylindrical boilers, to which it is fastened by the water-legs C C. The object of this arrangement is to provide for the collecting and retaining of the sediment contained in the water in the coolest portion of the generating apparatus. An air-duct *b* and a mixing-chamber H for the admission of air from the ash-pit, L, to mix with the gases of combustion, are also peculiar to this boiler. D D are walls for setting; E, the pier; F, connected parallel upright walls; *g*, the return flue; G, the fire-place; I, J, the bridge-walls; *d d*, flues.

Fig. 957 is a longitudinal vertical section of the Field boiler. The furnace is constructed of brickwork in the ordinary manner, a large flue or chamber being formed at the back, into and

957.

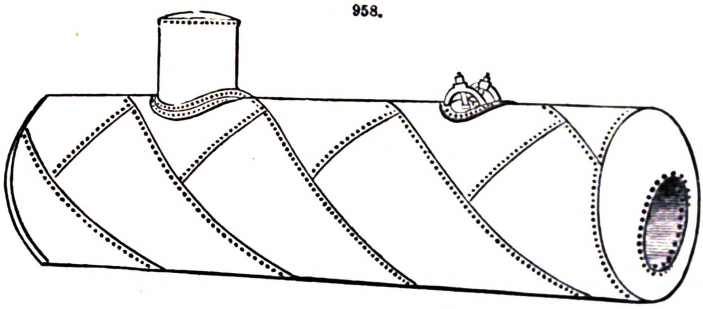



through which the heated products of combustion pass to the chimney. Across this flue or chamber are placed a number of inclined cast-iron tubes *a*, connected by flanged joints with bolts and nuts at their higher extremities to a longitudinal cast-iron tube *b*, constituting the main steam-space. A corresponding longitudinal cast-iron tube, similarly connected to the lower ends of the inclined tubes, and protected by brickwork from the direct action of the products of combustion, serves as an equivalent for the water-casing employed in the ordinary vertical Field boiler, and constitutes a receptacle for the collection and deposit of sediment. The under-sides of the inclined cast-iron tubes have bosses cast upon them, as shown, and tapering holes are bored, into which the wrought-iron *Field tubes*, *d*, are drifted in such manner that they hang down into the flue. On the upper part of the inclined pipes are formed a number of bosses, through which holes are drilled above each of the Field tubes, and rather larger in diameter than the latter, thus affording ready means of access not only to them but likewise to other parts of the interior of the boiler. Each hole is closed by a tapering plug, secured in its position by two bolts and nuts. The radiation of heat is prevented by iron plates resting on ledges above the inclined tubes, and covered with ashes. Cast-iron plates are placed across the upper and lower parts of the flue, for directing the course of the products of combustion, so that they may impinge in the most efficient manner upon the Field tubes, the circulation of the water in which is of a very perfect character.

Wright's diagonal seam boiler is shown in Fig. 958. It will be observed that in this boiler no three corners meet; this renders the boiler much stronger than the ordinary straight seam boiler.

Figs. 959, 961, show sections of Hawksley, Wild, and Co.'s single-flued, and Fig. 960 cross-section of their double-flued boiler. The flue is strengthened by flanging the smaller rings of plate; each flange in this flue is an expansion-joint, which allows the separate rings to expand and contract without increasing the steam upon the ends or shell of the boiler. A, Fig. 961, shows the combustion-chamber.

958.



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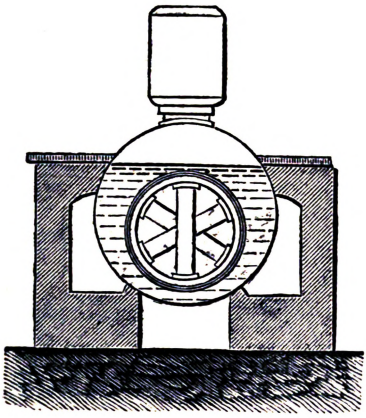

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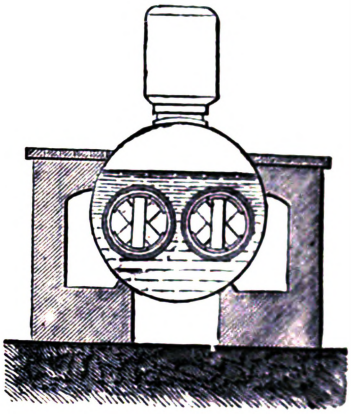
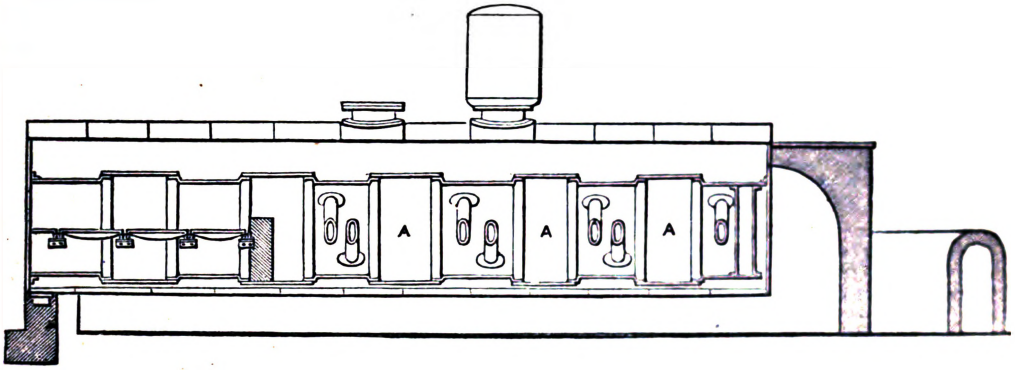


961.




Martin Benson's high-pressure boiler is shown in Figs. 962 to 964. Fig. 962 is a front elevation, showing the receiver and circulating pump; Fig. 963 is a longitudinal section of the boiler, and Fig. 964 a transverse section at right angles to Fig. 963.

The boiler is composed entirely of tubes, A, Fig. 963, arranged in a series of horizontal rows over the fire. B B are doorways at the front and back of the boiler, for fixing, disconnecting, and taking out the tubes. C, Fig. 962, is the water and steam receiver; D the circulating pump, which draws its supply of water from the receiver C, and is worked by the small donkey-engine E above. F is the main supply-pipe from the circulating pump, to which the lowest tubes of each section of the boiler are connected. G is the main delivery-pipe, to which the top tubes of each section are joined, and into which the water and steam together are delivered from the tubes and thence discharged into the upper part of the receiver C.

The steam generated in the tubes is driven up with the water through the tubes and discharged through the pipe G into the receiver C, where the steam and water are separated, and the water is then again taken by the circulating pump and returned into the tubes. In starting the boiler, the receiver is supplied with water until its level reaches the fifth or sixth row of tubes from the bottom, as shown by the dotted line; as the circulating pump is standing still at first, in consequence of having no steam to work it, the slide-valve is allowed to be lifted off its face by the pressure of the water, and lets the water flow past the pump direct through into the tubes. The fire is then lighted and steam raised from the water in the tubes, which starts the circulating pump to work.

Benson's boiler was first introduced in the United States, but the one we have described has for many years supplied steam for a 60-H.P. steam-engine at James Russell and Sons' works at Wednesbury.

962. 963 964.

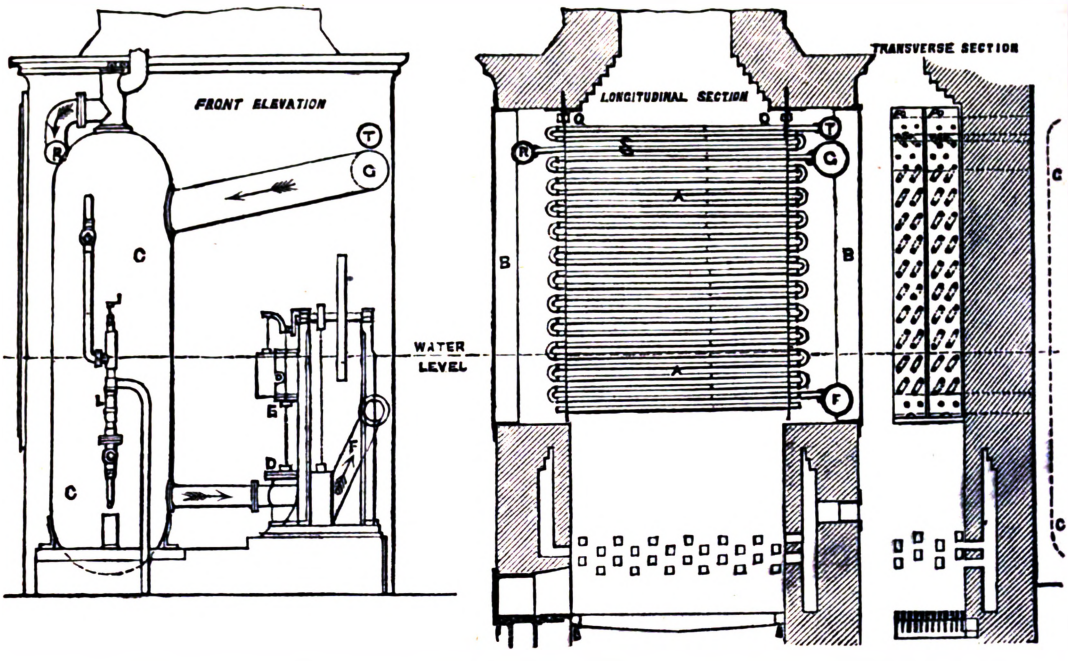
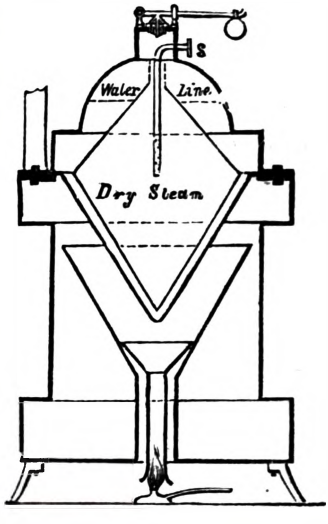



Fig. 965 shows one of Loader and Child's boilers. The principal feature of this boiler is the introduction of a reservoir or steam-chest in the centre or heart of the boiler, which receives the steam as it is generated, thereby providing dry, and, to a considerable extent, superheated steam; and at the same time the action of this boiler is to throw a thin body of water to the heating-surfaces, by which means steam is rapidly generated by a small quantity of concentrated heat.

965.




The boiler, Fig. 965, is the one which Loader and Child construct for small purposes. It has a cast-iron vertical case, with a copper cone or shell; the supply-tank is formed round the case and sides, and is heated by the flues on the reverse side. By this means much of the heat is utilized. The boiler shown in Fig. 965 is usually heated by gas when not more than 2-horse power is required, but this boiler is easily arranged so that ordinary fuel may be employed.

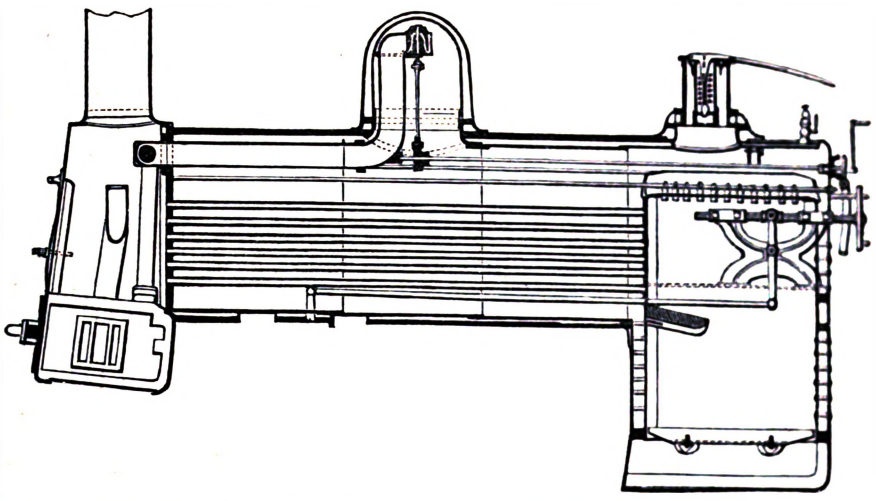
*Locomotive Boilers.*—We give, with some alterations, the following illustrations of locomotive boilers from Zerah Colburn's valuable work on 'Locomotive Engineering.'

In a locomotive boiler the outside and inside fire-boxes are made, the former of iron and the latter of copper. The water-space between them, and which completely surrounds the inner fire-box, is closed at the bottom by a square bar. This bar is bent and welded to the proper form, to extend around the bottom of the inside fire-box, and it is riveted and tightly caulked to both fire-boxes. The water in the water-spaces is in free communication with the rest of the water in the boiler; and thus the flat sides of the respective fire-boxes are exposed to the full pressure of the steam, which tends to burst the outside fire-box, and to collapse the inside fire-box. These flat sides, by themselves, would be unable to resist the strain upon them; but as the strain upon the respective fire-boxes is in opposite directions, and necessarily equal for equal areas of surface, tie-bolts, or, as they are called, stay-bolts, are screwed through the plates at frequent intervals, so as to connect the two fire-boxes securely together, the ends of the stay-bolts being also riveted, or spread out by hammering so as still further to increase their holding power.

The flat top of the inside fire-box is of course equally weak with the sides. It could not be satisfactorily secured by stay-bolts to the roof of the outside fire-box, and it is stiffened, therefore, by a series of iron bars, placed on edge, and of considerable depth, and which are firmly connected to the roof or crown of the inside fire-box by rivets. The roof, therefore, can only be crushed downwards by bending these bars, which are of great strength, at the same time. These bars usually extend in the direction of the length of the fire-box, as shown in Fig. 966; but they may extend across it, as shown in section on the roof of the inside fire-box in Fig. 967. These stay-bars bear on the fire-box only for a short distance at each end, iron rings or washers being

interposed between them and the roof-plate at the points where the bolts or rivets which secure the bars pass through. This permits the water to circulate under the bars, and prevents the roof-plate from being burnt, as it would be if the water were excluded from the whole under-surface of the stay-bars.

966.



A horizontal grate of thin and deep bars is fitted across the bottom, forming the bottom of the fire-box; and a door is made to open into the fire-box from the foot-plate. The opening for the door has to be made through the plates of both fire-boxes; and in order to keep the water-space tightly closed, a ring of iron, of which the inner diameter corresponds with that of the door, is riveted between the outside and inside plates.

Thin brass tubes, generally 2 in. in diameter, and from 10 ft. to 12 ft. long, are employed to conduct the hot gases from the fire-box to the chimney, the number of tubes varying, according to the size of the engine, from 100 to 200, or more. The arrangement of these tubes, the uppermost row of which is covered by from 6 in. to 8 in. of water, is shown in all our sections of locomotive boilers. The front plate of the inside fire-box and the front plate of the cylindrical portion of the boiler are accurately drilled, to receive the ends of the tubes, which pass through the plates, and are made steam-tight within them by means of ferrules of wrought or cast iron, which are driven into the ends of the tubes, so as to force them tightly into contact with the interior surfaces of the holes in the tube-plates. Such is the tightness with which the tube-ends are thus secured in their plates, that not only is there no leakage of water, as long as the joints are kept in good order, but the tubes serve as ties to prevent the respective tube-plates from being forced outwards, as they otherwise would be, by the pressure of the steam. Through that portion of the boiler above the tubes a number of tie-bolts extend longitudinally from the smoke-box tube-plate to the back-plate of the fire-box, to hold these plates together against the pressure of steam tending to force them apart.

The tubes lead into a closed chamber, formed upon the front end of the boiler, and called the smoke-box. Although the smoke-box has a removable door in front, this is tightly closed when the engine is ready for working, and then there is no inlet of air to the smoke-box except through the tubes, and no outlet except by the chimney.

Before steam is raised, and when the boiler is empty, it is first filled with water to the height of a few inches above the fire-box, by means of a hose connected with a cock placed on any convenient part of the boiler. In order to know when the water is at the right height there are two gauge-cocks fixed in the back-plate of the fire-box, towards the engineman's foot-plate, the one cock a few inches above, and the other as much below the proper level of the water within the boiler. These cocks have steam-tight fittings connecting them with a glass tube, within which the water, having free access from the boiler through the lower cock, is free to rise and fall, the surface of the water in the glass being under the pressure of the steam, freely admitted from the boiler through the upper cock. The water within the gauge-glass thus has the same level as that in the boiler; and the engineman has only to look at this glass to see what the height of the water is.

To prevent cinders and live coals from falling through the fire-grate upon the line, and partly for another reason, an *ash-pan* is fixed beneath the fire-box, and a few inches off the rails.

It is often important, when the engine is standing, to prevent any access of air to the fire-box; and hence the ash-pan is made to fit tightly to the fire-box on all but the front side. This side is opened or closed at pleasure by a hinged plate, called the damper, which is adjusted by a rod worked from the foot-plate. When the engine is running rapidly, with the damper open, a slight advantage is also gained by the rush of air into the ash-pan. At 60 miles an hour, or 88 feet a second, the pressure of the air against the moving surface would be over 1 oz. a square inch, or 9 lbs. a square foot. For countries where much snow falls, it is necessary to have a damper also at the hind end of the ash-pan, as otherwise it would soon become choked with snow when there was more than a few inches in depth of this upon the ground. In going forward, the front damper is then closed and the hind one opened.

The particulars we have just given are well illustrated by Fig. 966, which is a section of a boiler designed for a goods locomotive by John Ramsbottom. Fig. 966 also shows the steam-dome and steam-pipe.

Fig. 967 indicates the type of boiler used for passenger locomotives by the Rogers Locomotive and Machine Works, U.S.

967.

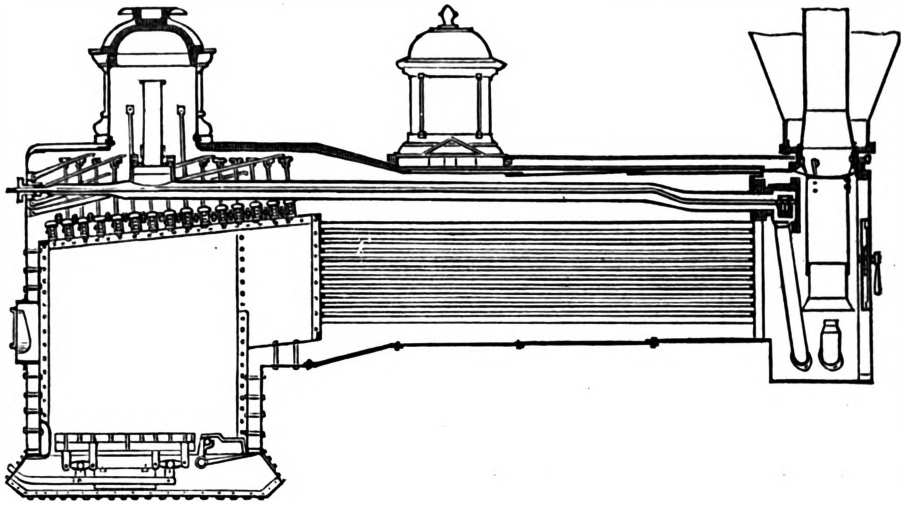
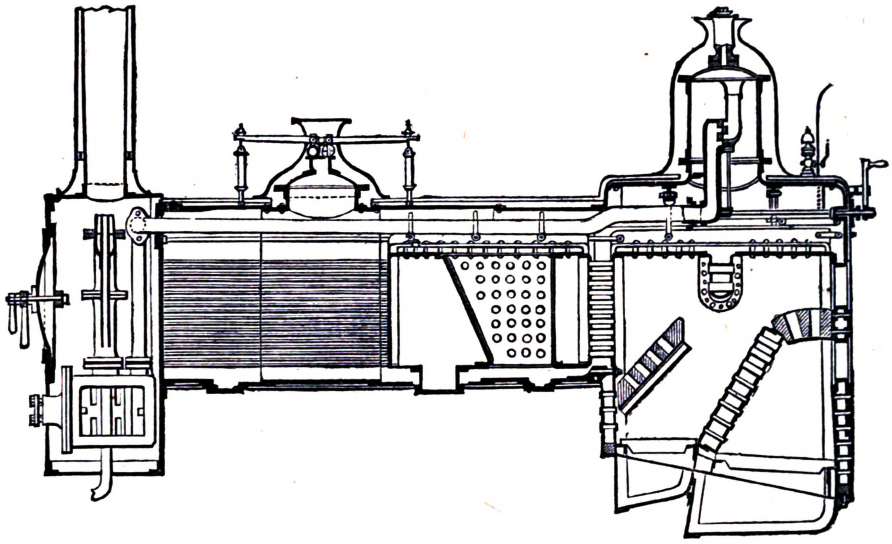


Fig. 968 represents the boiler designed by Joseph Beattie, and used on the London and South-Western Railway, for burning coal without smoke. The fire-box is divided by an inclined water-partition into two compartments, each having its own door, fire-grate, ash-pan, and damper. The principal fire is maintained in the box nearest the foot-plate. The gases rising from the coal are

968.



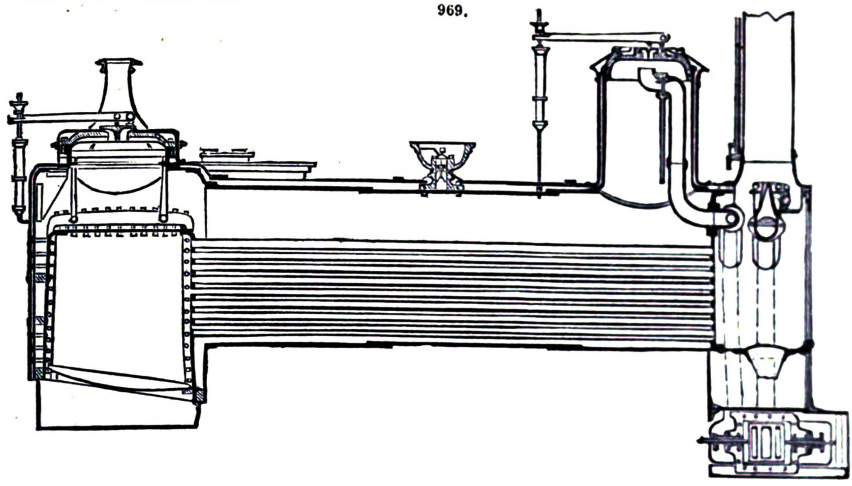
met by a number of fine streams of air entering through the perforated door, and both the gas and air rise through a grating of fire-clay tiles into the upper part of the second fire-box, on the grate of which coal is burnt only slowly, with a slight and carefully-regulated admission of air through the front damper.

The mingling air and gases are deflected downwards by a hanging water-bridge, over a fire-brick arch and through a series of fire-clay tubes into a combustion-chamber 4 ft. 6 in. long, from which more than 375 small boiler-tubes lead into the smoke-box.

The boiler shown in Fig. 969 was designed by John Haswell for the Austrian State Railways. It is used in steep-gradient locomotives for curves of 275 ft. radius.

Fig. 970 shows the form of boiler constructed by James Cross for passenger engines on the St. Helen's Railway.

969.



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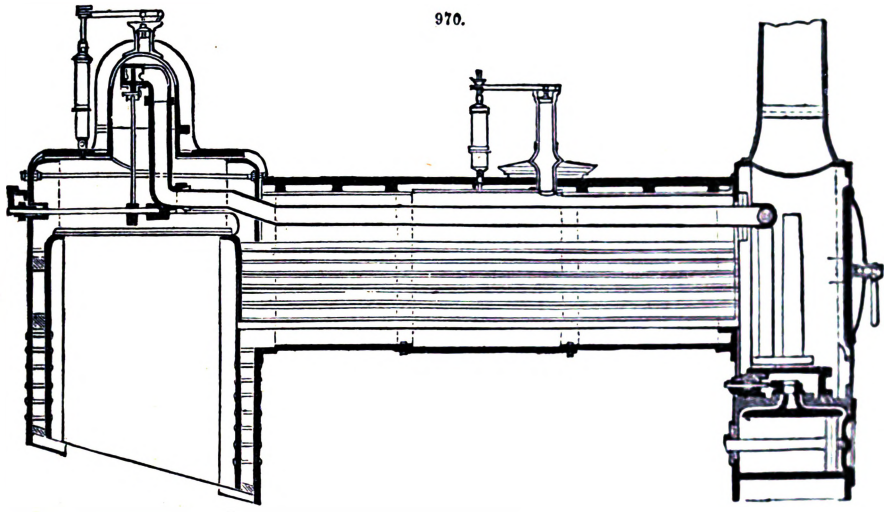


Fig. 971 represents the boiler for a passenger locomotive constructed by Robert Stephenson and Co. for the Stockton and Darlington Railway.

971.

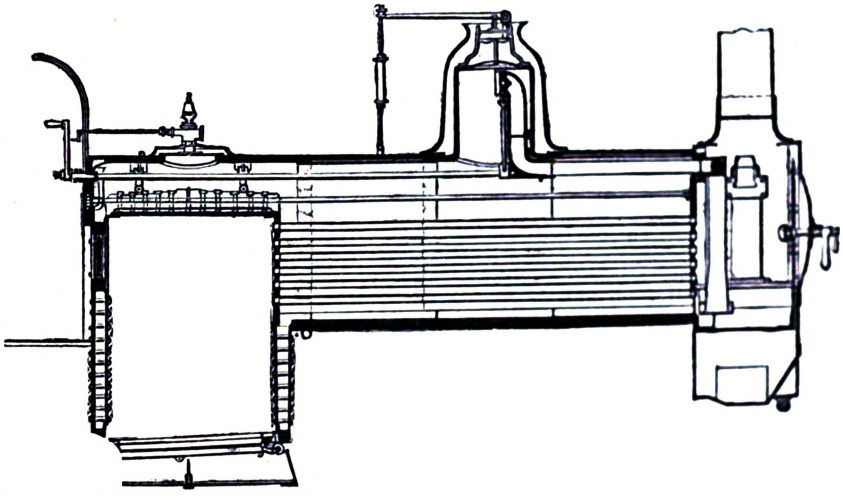


Fig. 972 is the type adopted on the South-Eastern Railway for coal-burning coupled passenger-engines.

972.

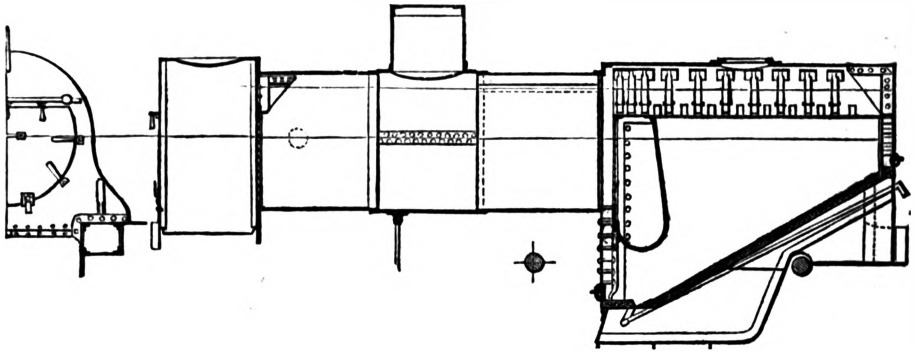
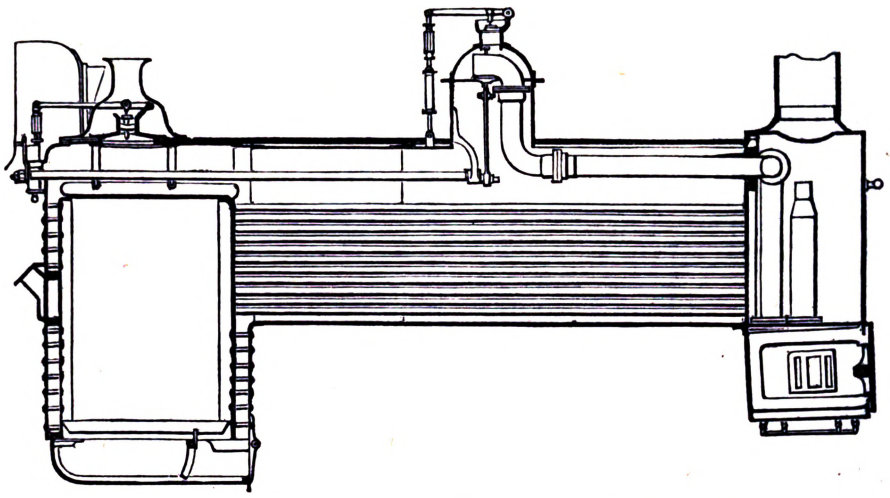


Fig. 973 exhibits a boiler for a goods engine used by John Wakefield on the Great Southern and Western Railway, Ireland.

973.



Of all the boilers we have enumerated, none is superior to the *Whittle* boiler.

See CONDENSERS. CORNISH ENGINES. DETAILS OF ENGINES. ENGINES, *varieties of*. EXPLOSIONS: *Boiler*. FUEL. GEARING. INCRUSTATION *of Boilers*. JOINTS: *riveted*. LOCOMOTIVES. MARINE ENGINES. PARALLEL MOTIONS. PYROMETERS. SLIDE-VALVES. STATIONARY ENGINES. STEAM and the STEAM-ENGINE. VALVES.

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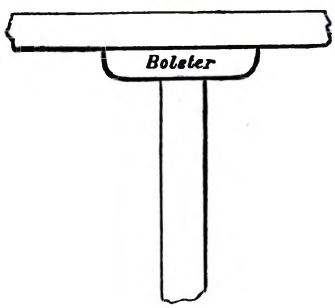



See also papers by Dunn, Colburn, Russell, Perkins and Williamson, Longridge, Goodfellow, Spencer, and others, in the 'Transactions of the Institute of Mechanical Engineers,' and papers by various authors, in the 'Trans. Inst. Naval Architects.'

BOILER-PLATES. FR., *Tôle à chaudière, étole*; GER., *Kesselplatten*; ITAL., *Lamiera da caldaie*.

See BRIDGES. RIVETED JOINTS. STRENGTH OF MATERIALS OF CONSTRUCTION.

BOLSTERS. FR., *Estampes, perçoires*; GER., *Lochscheiben*; ITAL., *Cuscinetto*.

*Bolster.*—In carpentry, a short piece of wood, Fig. 974, interposed horizontally between the head of a post and a beam which it supports. It is also called a *corbel-piece*, as it shortens the bearing between the posts. The chief use, however, of a bolster is to prevent the head of the post crushing into the part of the beam which rests on it, when the latter is heavily loaded. Bolsters are generally used in timber bridges, masons' scaffolding, and so on.

The term bolster has also been applied to the pieces of timber placed across the ribs of the centering of an arch to support the voussoirs; but these are more generally known by the name of *laggings*.

BOLTING MILL. Fr., *Blutoir;* Ger., *Beutelmühle;* Ital., *Buratto, Frullone;* Span. *Cedazo.* See Barn Machinery.

BOLTS. Fr., *Boulons;* Ger., *Bolzen;* Ital., *Chiodi a perno;* Span., *Grillos.* See Nuts and Bolts.

BOND. Fr., *Appareil, Assemblage;* Ger., *Mauerverband;* Ital., *Legamento dei mattoni.*

*Bond* is a mode of connecting two or more bodies by overlapping.

In *Brickwork* and *Masonry*, it is the mode by which a number of small pieces are combined to form a large mass so that no joint in a course shall occur over a corresponding joint in the next course, which is termed breaking joint.

Bricks are usually in length about twice their width, and in thickness about one-third of the length. For bonding, however, the latter dimension is not of much importance, provided it is uniform in all the bricks of a course.

When a brick is so placed in a wall that its greatest dimension is at right angles to the face, it is called a *header*, and when parallel to the face it is called a *stretcher*.

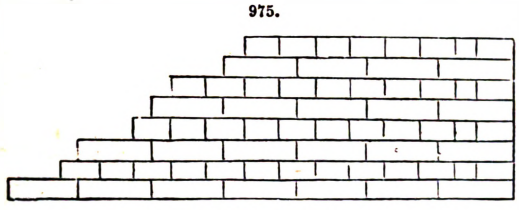
The methods of bonding brickwork generally adopted in England, are known as Old English Bond, Flemish Bond, and, to a limited extent, Garden-wall Bond.

In Old English Bond, Fig. 975, a course of headers alternates with a course of stretchers.

In Flemish Bond, Fig. 976, headers and stretchers are placed alternately in *each* course.

In Garden-wall Bond, Fig. 977, one header is placed at the end of every three stretchers in each course.

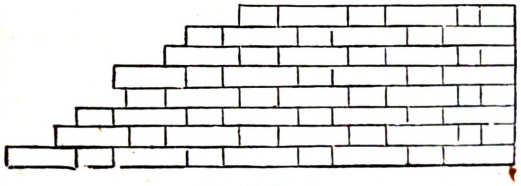
Of the three methods of bonding, the Old English is the strongest, and takes less time to build than Flemish Bond; the joints are more uniformly broken than in the others, fewer *bats* or broken bricks are required to make the work solid, it contains more headers, and consequently there must be a better tie between the face and heart of the wall.



975. Old English Bond.

978. 1 Bk.

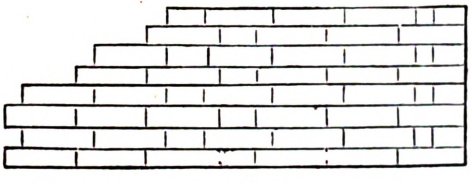
979. 1½ Bk.



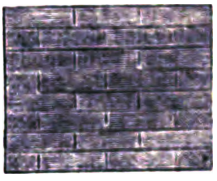
976. Flemish Bond.

980. 2 Bks.

981. 2½ Bks.



977. Garden-wall Bond.



982. 3 Bks.

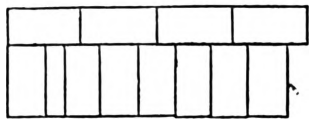
Figs. 978, 979, 980, 981, and 982, show sections of walls in Old English Bond, from one to three bricks in thickness, with mode of bonding the heart of such walls.

Flemish Bond is considered to have a neater appearance; and in cases where a wall is faced with bricks of a superior quality, a less number is required than in Old English Bond.

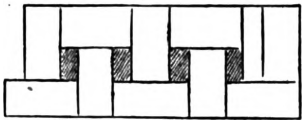
Fig. 983 is a course of bricks laid in Old English, and Figs. 984 and 985 are courses laid in Flemish Bond; in the former the bricks all fit close together, and none of them require to be broken, or snapped, as it is termed, except the closer, the reason for which will be explained

presently. In the latter the headers must either be snapped, as in Fig. 985, or the heart of the wall filled up with small pieces of bricks, as in Fig. 984.

983.

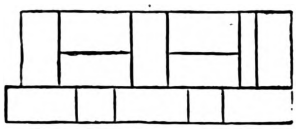


984.



Garden-wall Bond is, as the term implies, chiefly used in the one-brick walls so frequently seen between the back-yards or gardens of town residences. The necessity of preserving a fair face on *both* sides of the wall is the cause of this bond being used, as, owing to the difficulty of procuring bricks all of one size, it is impossible to build a wall one brick thick in which both of the sides can be worked fair, in either English or Flemish Bond, particularly the former. This is shown in Fig. 986, which is a course of headers laid in English Bond.

985.



986.

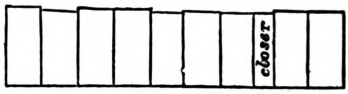


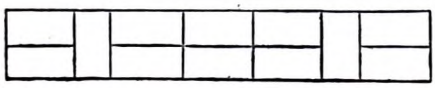

Fig. 987 shows how, by the use of Garden-wall Bond, this irregularity in the size of the bricks is rendered less apparent.

One-brick walls are frequently built in Flemish Bond, but one-half of the headers require to be snapped, which leaves no more cross-tie than Garden-wall Bond, while the longitudinal tie is not so good.

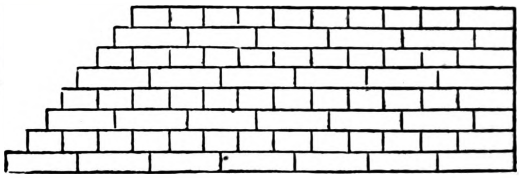
In half-brick walls stretchers only are used; this is called chimney bond.

In Belgium and north of Germany the system of bond used is that called **Kruisverband**, Figs. 988 and 989.

987.

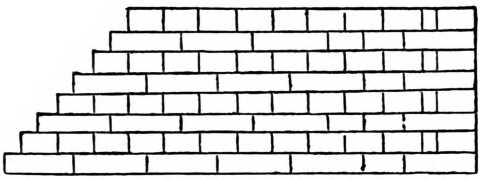


988.



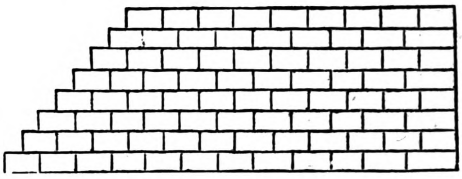
Kruisverband.

989.



Kruisverband.

990.

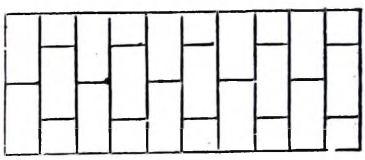


French Military Engineers' Bond.

The heading and stretching courses are as in Old English Bond, but the alternate stretching-courses *break* joint, while the joints of the corresponding heading-courses fall one over the other as in Old English Bond. As more of the joints are broken than in the other method described, this bond is considered to be the strongest of any. It does not, however, present so uniform an appearance as the Flemish or Old English.

The French Corps du Génie prefer to build the face of their walls with all headers, as in Fig. 990; but to obtain a tie between the face and heart of the wall, they place alternately in each course a half-brick, or *bat*, as shown in Fig. 991.

991.



This mode they assert has the advantage of offering more resistance to disruption than any other. The longitudinal tie, however, is not so complete as in the English and Belgian systems, the joints being about one-tenth more numerous, and the waste occasioned by cutting the bricks is greatly to its disadvantage.

In the heart of a thick wall it is considered advantageous to lay occasionally a course of bricks

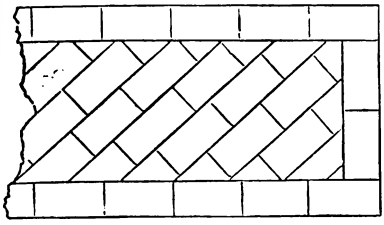
in a direction inclined to the face, as in Fig. 992. It is known by the name of Diagonal Bond, and when the direction of the brick is reversed in the next course this system adds strength to the wall; but it is attended with the disadvantage of having to cut the bricks to fit the back of those on the face.

From the fact that bricks are made in width equal to half their length, it becomes necessary, in order to break joint between the bricks of two adjoining courses, whether they be laid as headers or stretchers, to insert a quarter-brick in one of them at starting. This is called a king-closer, and is usually inserted in Old English Bond after the first brick is laid in the heading-course, and in Flemish Bond after the first headers. They are shown in Figs. 975 to 977.

In the French, and sometimes in the Belgian methods of bonding, the same result is obtained by starting one of the two adjoining courses with a stretcher cut to three-quarters of the usual length, called a queen-closer.

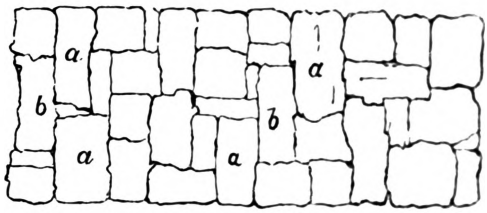
The bond adopted in *Ashlar* masonry is similar to the bond used in brickwork; closers, however, are seldom used in masonry, as the stones in the courses can be cut to any length required to make a perfect bond.

992.



Diagonal Bond.

993.




Plan.

In walls of rubble masonry from 1 ft. to about 3 ft. thick, it is usual to have at intervals of from 4 to 6 ft. a stone called a thorough, which runs from the back to the front, and so binds the wall together; but in thick walls, owing to the great length of the stone required, two stones of as great length as can be procured are made to lap in the middle of the wall; and in very thick walls, where stones cannot be found long enough to lap in this way, a third stone *b*, Fig. 993, called a tail or *heart bond*, is used to connect the two *bond-stones* or binders in the face of the wall.

Various special modes of bonding have been adopted in works of masonry where great strength is required, as in sea-walls and similar constructions. That used by Smeaton in building the Eddystone lighthouse consisted of a system of dovetailing and dowelling, for a detailed description of which the reader is referred to his account of this great work. See CONSTRUCTION. MASONRY.

*Bond-Course.*—A course or horizontal layer of some material built at intervals into a wall in order to strengthen it.

When of brickwork, and built into rubble-stone or flint walls, it is termed a *lacing course*.

In brick walls built with ordinary mortar, two or three courses of bricks in *cement* are sometimes laid below the floor-line of the basement story of dwellings to prevent damp rising. In this case they would be called a damp course.

Formerly, courses of wood-bond, called chain-bond, were much used in building where there were usually one or more tiers to each story. The size was about 8½ in. wide by 5½ in. high, or equal to the space occupied by a course of brickwork two bricks in height and two in width.

These bond-timbers went all round the walls and cross-walls, and through openings, from which they were afterwards cut out. They were connected at the angles, and no doubt tended much to strengthen the building for a time; but sooner or later decay set in, and the destruction of the building was the consequence. That and the increased danger from the effects of fire rendered chain-bond objectionable, which has in later years caused it to be almost abandoned.

*Common bond* of fir, 4½ in. wide by 2½ to 3 in. thick, is now more generally used, less as a bonding-course than a means of fixing battens or other finishings which are nailed against the wall.

When common bond is used solely for fixing battens, it is called *ranging-bond*, and is usually placed at intervals of from 18 in. to 3 ft., according to the strength of the battens.

Though common bond is open to the objections urged against chain-bond, but in a lesser degree, its use is preferable to plugging the walls where much of the latter is required, or even to the insertion of wood bricks, which are only short pieces of common bond about the size of an ordinary brick. The act of driving plugs shakes the wall, and destroys the adhesion between the bricks and mortar, and wood bricks shrink in time and drop out.

Ranging-bond should project a little beyond the face of the wall to permit a free circulation of air at the back of the battens or other work which has been fixed to it.

Common bond is usually described in specifications to be put all round each story in one or more tiers; all joints to be properly lapped at least 6 in., and the angles halved and notched or cogged. No bond-timber should be permitted in an underground story, as its decay would be more rapid and the danger to the brickwork resting upon it greater than in the upper stories.

When walls require strengthening by the use of bond-courses, *hoop-iron* is much to be preferred to wood. By its use Isambart Brunel, in 1835, managed to construct two half-arches of brickwork in lias-lime mortar, projecting 40 ft. from each side of a single pier, without any support at the other end.

Although only 4½ ft. wide on top, after another 20 ft. in length had been added to one end, a

counterpoise of 28½ tons was added to the other; yet it bore this enormous weight for upwards of three years, and probably would not then have given way if it had not been for a considerable settlement which had taken place in the foundations. Cracks appeared in the work, and, the wet getting in, it expanded during a severe frost, and so caused the failure of this wonderful piece of construction.

Several pieces of hoop-iron, 1½ in. wide and $\frac{1}{20}$th of an in. thick, were used; also pieces of fir, 1½ in. square, which did little more than assist in retaining the bricks until sufficient adhesion had taken place with the mortar to allow the hoop-iron to take effect.

Hoop-iron bond had also been used by Brunel in the large circular shafts, 50 ft. in diameter, leading to the Thames Tunnel, which were built above ground, and lowered into their places—a depth of 42 ft.—by excavating underneath, an operation successfully performed without a crack or flaw, which was considered to be due in a great measure to the use of the hoop-iron.

To prevent decay when in contact with the wet mortar of the walls, the hoop-iron should be well coated with a mixture of tar and pitch, and afterwards with sand. The form in which it was most generally used in building is that known as Tyerman's Patent Hoop-iron Bond, from 1¼ to 2½ in. wide, and from No. 6 to No. 15 Birmingham wire-gauge in thickness. It is prepared from the ordinary hoop-iron by notching it at intervals of 12 in. on both sides alternately, Fig. 994, and turning in succession, in contrary directions, a triangular piece, so as to form claws, which catch in the brickwork and effectually prevent its being drawn out by any force short of tearing the iron asunder. In modern practice, however, the notching has been considered unnecessary.

994.

Tiers of two or more strips, according to the thickness of the wall, laid at every 3 ft. in height, have been considered sufficient in most cases. The mode of laying each tier is to place a strip on every half-brick in the thickness of the wall, continued over the whole length of the work, regardless of openings, as in wood-bond. Afterwards the parts across the openings are cut so as to leave a short piece protruding, which should be turned down against the face of the *jamb*. At all junctions it should be lapped, and the pieces carefully hooked to each other.

In footings or in thick walls exposed to great strains, strips of hoop-iron should be laid diagonally, interlacing with those laid in a longitudinal direction.

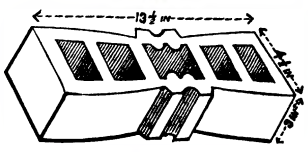
Bonding-courses of dressed stone have been used with advantage; they should be cramped together at each joint.

The ancient Romans used a large flat tile, about 2 ft. long by 18 in. wide, laid at intervals of about 4 ft. in height. Bonding-courses of this description, however, are more applicable to rubble masonry than to block-stone or brickwork.

*Bonding-bricks* are bricks of greater length than those of which the wall is built. They are used in hollow walls to tie the two faces together. Their length should be as much longer than the ordinary brick as the space over which they bond.

Some very effective bonding-bricks have been introduced by a London manufacturer, the ends of which are of a dovetail shape, Fig. 995; and, where the precaution is taken to cut th adjoining bricks to fit, nothing can be more effective.

995




These bricks are usually made non-absorbent, by being glazed, so that damp cannot be conveyed by them from the outer to the inner skin of the wall.

When ordinary bricks are used in this way for bonding, they should be dipped in boiling pitch, or tar, to prevent the damp passing from wall to wall.

BOND-COURSE. Fr., *Chaine;* Ger., *Band;* Ital., *Catena.*

See Bond.

BOND-TIMBER. Fr., *Pièce d'assemblage;* Ger., *Binde Hölzer;* Ital., *Catena.*

See Bond-Course.

BONE-MILL. Fr., *Moulin à os;* Ger., *Knochenmühle;* Ital., *Frantoio delle ossa.*

The mill invented by E. P. Baugh for grinding bones, ores, and other hard substances, is shown in Figs. 996 to 1001. Baugh's improvements refer to that class of cast-iron grinding mills, the cutting and triturating surfaces of which are made in the form of a frustum of a cone. The shell and burr are constructed of a number of cast-iron grinding sections, fitted and held together in a peculiar manner (which will be described presently), so that the sections can be readily removed to make way for others; the dress of the mill being thus rendered changeable to suit the substances to be ground; while the mill itself is more economical, both as regards its original construction and its lasting properties, and the variety of substances which it may be arranged to grind, than mills of the ordinary construction. The grinding sections of the shell are backed by an exterior casing, between which and the base, to which the casing is secured, are confined the sections, so that the latter can be readily disconnected from the mill. The several sections of the burr are secured to a block between a lip or ring, or other projection, at or near the lower edge of the latter, and a ring fitted to the vertical shaft, which carries the burr so that the sections can be readily detached. The ring, which aids in securing the grinding sections of the burr, has grinding teeth formed thereon, and a breaker or stirrer is fitted to and turns with the vertical shaft of the mill; provision being made for rendering it easily detachable therefrom, so that different forms of breakers may be applied to the mill. Certain detachable sections are used, acting in conjunction with the breaker for preliminary grinding; these sections being fitted to and backed by a casing, and held in position by a cap-plate secured to the same, and carrying the bearing for the vertical shaft which carries the burr. The vertical shaft, with its burr and other appendages, are supported on

a sliding step controlled by a lever and an adjustable weight, which tends to elevate the burr, but is limited in this tendency by a screw or other adjustable stop, the burr by this arrangement being maintained in the desired proximity to the shell, but being prevented from coming in contact therewith and injuring the grinding surfaces; the burr, at the same time, being at liberty to yield, should a piece of iron or other refractory material find its way between the grinding surfaces. In order to reduce friction and facilitate lubrication, a double cone of steel is interposed between the bottom of the vertical shaft and the bottom of the step in which the shaft turns.

Fig. 996 is a half section and elevation of the improved mill; Fig. 997 is a sectional plan of the upper portion of the mill; Fig. 998 is a similar view of the lower portion; and Figs. 999 to 1001 are details, which will be referred to hereafter. A is the base-plate of the mill, secured to a foundation B, and on this plate are fitted suitable bearings *a a* for the horizontal shaft *c*, the latter being furnished at one end with a fly-wheel, and between the bearings *a a* are fast and loose pulleys *b b'*. At the opposite end there is a bevelled pinion F, gearing into a bevel-wheel G, which is so secured to a vertical shaft H, that both must turn together, while the shaft is at liberty to slide up and down through the boss of the wheel. This shaft has its lower bearing in a step I, shown on a larger scale at Fig. 1001, in a casing V, and which is secured to the base-plate A, as are also four columns J J, which support the lower plate K of the mill and its superstructure.

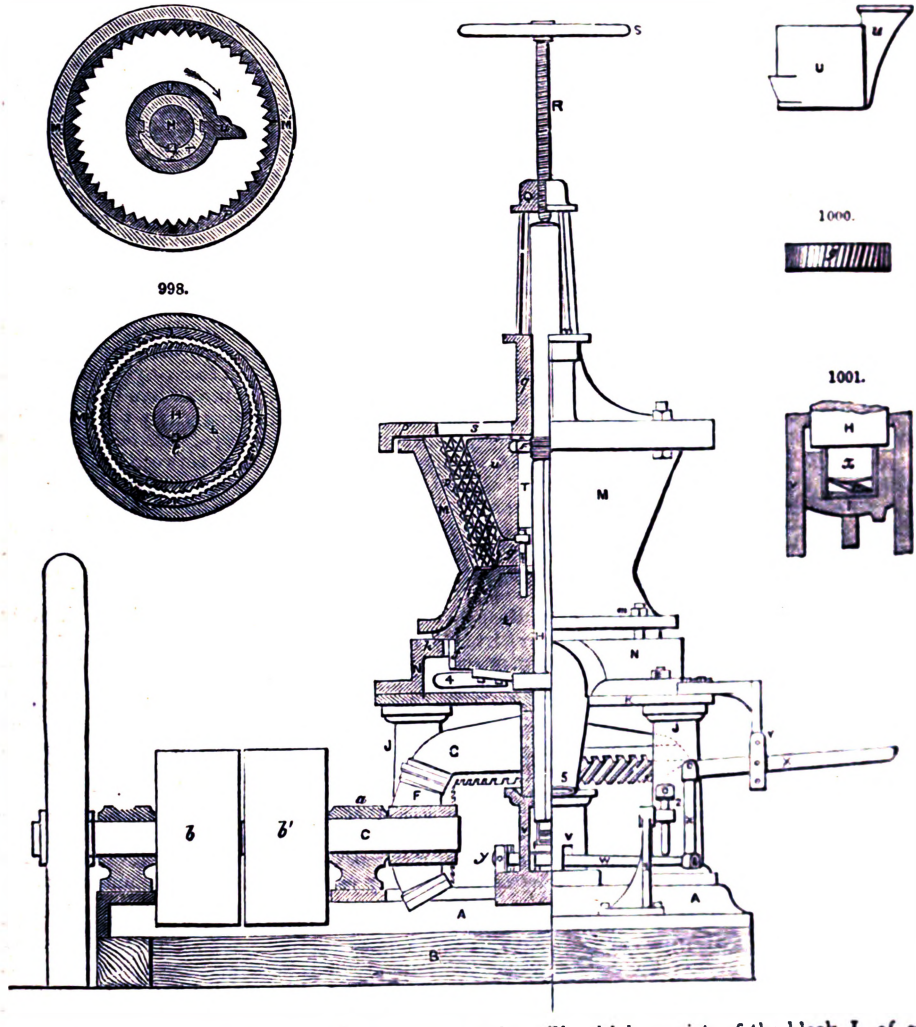
997.



998.



996.

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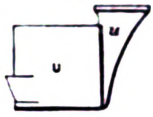


1000.



1001.




To the vertical shaft H is secured the burr of the mill, which consists of the block I, of cast iron, and the detachable cast-iron grinding sections *e*, the block being of the form, or approximating to the form, of the frustum of a cone, the sections conforming in shape to that of the block, and being secured thereto in the following manner:—Round the lower edge of the block there is a ring *f*, and against the inside of the upper projecting portion of this ring bear the lower ends of the detachable cast iron sections *e*, the latter having at their upper ends lips or flanges bearing on the top of the block, and confined thereto by set screws or bolts *h*. The form of each section is such, that one section will fit accurately against the adjacent section, the whole of the sections thus forming a continuous grinding surface.

The shell of the mill also consists of a number of cast-iron grinding sections *i*, fitted together edge to edge, and backed by an outer casing M, of the form, or approximating to the form, of a frustum of a cone, to which casing the sections are fitted, and by which they are held in place, the lower ends of the sections being confined between the flange *j* of the casing M, and the flange *k* of the cast-iron ring N, by bolts *m*, which secure together the casing and the ring, the latter being confined to the plate K by bolts *n*. In the present instance the case M is carried upwards in the form of an inverted frustum of a cone, and is lined with detachable cast-iron sections *p*, which are held in place by the cap-plate P, secured to the top of the casing M′, this plate having openings *s s*, and a central boss *q*, through which the shaft H passes, and in which it turns.

A stationary nut Q, connected to the boss of the cap-plate P, receives a screw R, the upper end of which is provided with a hand-wheel S. It will be seen that the shaft H has a feather *t*, adapted to a groove in the block L of the burr, and to a similar groove in the ring *g* of Fig. 1000, above which a sleeve T is fitted to and turns with the shaft, as it has a groove to receive the feather. To the sleeve is fitted what may be termed the breaker, Fig. 999, which consists of a boss U, having one or more projections *u*, the sleeve having grooves adapted to keys or feathers in the boss of the breaker, Fig. 997. Both the breaker U and the sleeve T, as well as the ring *g* and the burr, are confined by a nut *v* adapted to screw threads on the vertical shaft H.

The foot-step bearing I, previously alluded to, consists of a cast-iron box, arranged to slide in the cylindrical casing V secured to the base-plate A, and is furnished with a steel bush *w*, in which turns the lower end *x* of the vertical shaft H. Between the bottom of the shaft and the bottom of the bush intervenes a double cone *x′*, of hardened steel, made somewhat less in diameter than the shaft, as shown clearly in Fig. 1001.

A lever W, passing through a slot in the casing V, is hinged at one end to a pin on a stud *y*, secured to the casing, and bears against the under-side of the step I, the lever being connected at its opposite end by a link X to a lever X′, which is arranged for receiving a movable weight, and is hinged to a bracket Y, secured to the plate K; a set screw, 2, adapted to a nut on a stand, 3, secured to the base-plate A, serving to limit the upward movement of the lever X′.

Prior to setting the mill in motion, the lever X′ is so weighted as to more than balance the vertical shaft H with its burr and breaker, so that the said shaft may have an upward tendency, which, however, is limited by the set screw, 2, the latter determining the distance apart of the grinding surfaces of the shell and burr. By this arrangement the grinding surfaces are maintained in sufficient proximity to each other to act properly on the material to be ground, but will not come in contact with each other; at the same time, should a piece of iron or steel find its way between the grinding surfaces, the burr and shaft will yield and prevent injury to the mill.

The shaft H and its burr and breaker having been caused to revolve in the direction of the arrow, the bones, quartz, or other material to be ground, are passed through the openings *s s* in the cap-plate P, to the conical space bounded by the detachable sections *p*. Here, by the combined action of the teeth or dress on these sections, and the revolving breaker U, the material is fractured and reduced to comparatively small fragments when it has reached the ring *g*; by the combined action of the teeth on the periphery of which ring, and those near the lower portions of the sections *p*, the material is reduced to a condition which permits it to enter the space between the grinding sections *e* of the burr and those of the shell. As this space becomes gradually narrower towards the lower end of the shell and burr, the material becomes gradually reduced, and finally leaves the grinding surfaces in the desired pulverized condition, and falls into the space within the ring N on to the slightly concave surface of the plate K, where it is acted on by the revolving sweep, 4, the latter causing the discharge of the ground material through a spout, 5, into any suitable receptacle.

By making the grinding surfaces in sections, not only can both shell and burr be made truly round, but the teeth can be made of the most irregular character; for instance, the teeth or dress can be formed by grooves crossing each other, or some of the grooves may be straight, some curved, others diagonal, according to the nature of the material to be operated on. An indefinite number of changes may be made in the character of the dress when this mode of constructing the grinding surfaces of conical mills is employed, an important advantage, as the *dress* must be made to suit different materials, and in many cases different qualities of the same material to be ground; a dress for grinding bones, for instance, would be unsuitable in some respects for grinding quartz; and in operating on other substances it may be advisable for the dress of one section to differ from that of another in the same mill. It will thus be seen that the character of the mill may be entirely changed by a simple and speedy change of sections, and that when the teeth of one or more sections have become worn, broken, or otherwise inoperative, their removal, and the introduction of new sections, renews the mill, whereas an ordinary cast-iron mill would, under similar circumstances, have to be discarded.

In removing the grinding sections, the screw R plays an important part; for should it be desired to remove the sections *i* of the shell and the sections *e* of the burr, all that is necessary is to first detach the nuts of the bolts *m*, loosen the nuts of the bolts *n*, and the nut *v*, and then operate the wheel S, so as to cause the end of the screw R to bear on the top of the vertical shaft H, and continue to turn the screw until the entire shell of the mill is elevated so far as to permit the withdrawal of the sections of the burr and shell and the introduction of others, after which the shell is lowered by turning the screw in a contrary direction, the nuts of the bolts *m* replaced, and the nuts of the bolts *n*, as well as the nuts *v*, tightened.

Should it be necessary to remove the sections *p* only, the nuts are detached from the bolts which confine the cap-plate P, and the latter is elevated above the mill by operating the screw R when the sections are at liberty. After elevating the cap-plate clear of the shaft, the nut *v*, breaker *u*, and ring *g*, may be readily removed.

It has been found, after repeated experiments, that the double cone *x′* performs most efficiently the duty of distributing to the lower bearing the oil contained in the space between the bottom of

the shaft and the bottom of the step I, at the same time preventing undue friction at the point subjected to the greatest shocks and strains. This mode of interposing the double cone between the bottom of the shaft and the bottom of the step may be applied to the lower bearings of all vertical shafts, to the pivots of swing-bridges and turn-tables, and other objects having a vertical bearing to which great strains are subjected.

For grinding some materials it is not essential that there should be a superstructure M', and detachable sections *p*, or a breaker above the shell M, a simple hopper being in many cases all that is necessary to receive the material and direct it to the grinding surfaces; the latter, too, may (for grinding some materials) be straight instead of curved. It is preferable in most cases, however, to form teeth on the periphery of the ring *q*, as shown at Fig. 1000, so that it may serve the twofold purpose of aiding in the preliminary or first grinding, and of keeping the sections *e* of the burr in place. The lips of these sections *e* may, moreover, be dispensed with, the ring *q* bearing directly on the upper edges of these sections. The casing M, too, may be made in sections, or the grinding sections may be backed or held together by a suitable system of metal bands. See AGRICULTURAL IMPLEMENTS, p. 12, Fig. 27.

BOOT-MAKING MACHINERY. FR., *Machines à faire les bottes*; GER., *Maschine zur Anfertigung der Stiefel.*

The introduction of the sewing machine greatly facilitated the operations of boot and shoe manufacturers, and other workers of leather. The principal leather-sewing machines will be found in our article on *Sewing Machines*. But other boot and shoe making machines and tools are also employed to economize labour in this important branch of industry, the most useful and important of which are introduced under the present head.

1002.

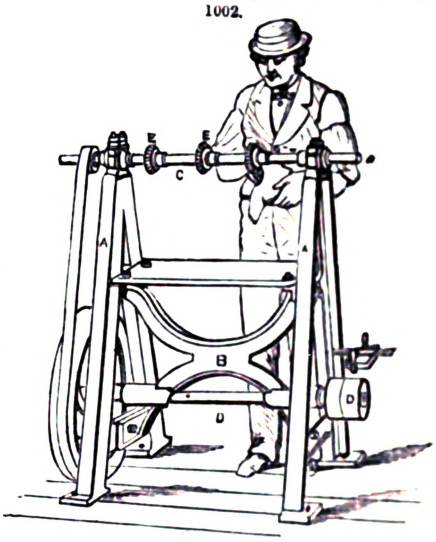
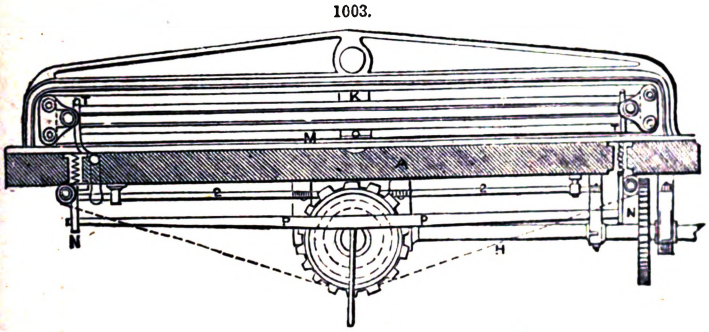


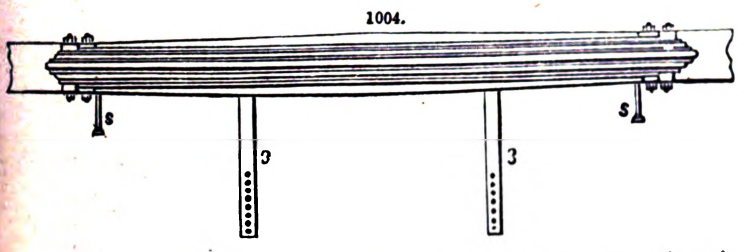
Fig. 1002 represents Gimson's machine for paring the edges of heels and soles of boots and shoes. This machine consists of two standards A with a stretcher B, a driving-shaft D which gives motion to a spindle *e* driven with high velocity; on this spindle, discs or circular cutters E are fixed; the boot or shoe is held against the cutter, the uppers being protected by a loose guard which runs in between the upper and the sole. These machines are easily worked; a man can pare at one of them twenty-four dozen pairs a day; they are fitted with an additional counter-shaft for gaining speed, so that these machines may be worked from a shaft of ordinary speed.

A primary operation in boot-making is that of cutting leather into strips for soles and heels. Jean Pierre Mollière's machine for effecting this is shown in Figs. 1003 to 1005. The leather being placed upon a table A, it is slipped under the frame: the traveller K being one of the extremities of the apparatus does not hinder this being done. To cut the edge of the leather straight, the leather is kept in position by means of a ruler M, which is a piece of iron with a longitudinal groove

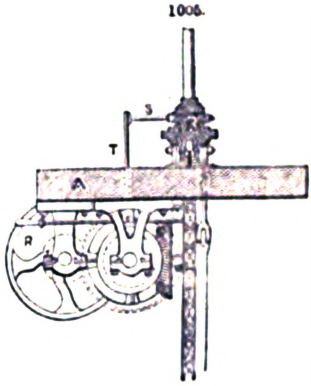
1003.



1004.



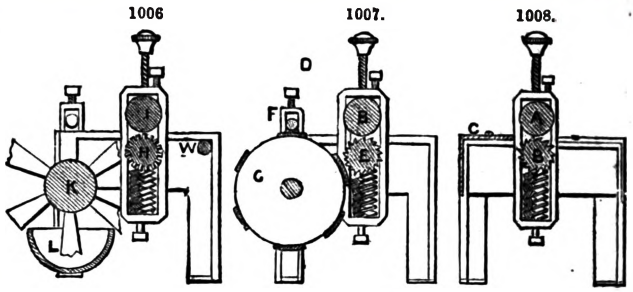
1005.



in it, in which the curved knife-blade or chisel O works when the ruler is down; and at each end of the groove is provided an opening into which the traveller K can pass. The ruler is

governed by two spring-rods N buried in the thickness of the table, and whose springs always tend to keep it raised: these rods are connected under the table by a yoke P attached to a treadle not shown in the figures.

When the leather is pushed under the rule, the treadle is depressed, thus pressing down the rule and keeping the leather firmly in its place. The handle R is then moved, throwing the parts for moving the chain into gear, and thus setting K in motion and cutting the leather. Arrived at the end, the traveller encounters one of the fingers S attached by levers T to a rod Q, forces it forward, and throws the chain out of gear, thereby arresting the traveller. The traveller is then let up, which will allow the springs N to throw up the ruler M, so as to let the leather pass, which is then cut straight. The workman pulls the leather towards him until its smooth edge comes up to the two pins 3, and then the operation just described is repeated.




In preparing leather for uppers upon C. Rice and S. H. Whorf's plan, Figs. 1006 to 1008, the skin is first introduced between the feed-rollers A, B, of the splitting mechanism, and by them is forced against the knife C; the upper portion of the skin split by the knife C passes towards and between the draught-rollers D, E, which move it forward between the roller F and a rasper G, which latter roughens the under-surface of it. From the rasper the leather moves over a guide-bar W, between the pressure-roller I and the perforating-roller H; and finally it passes between the roller, and a brush K, which latter revolves through a vessel L containing cement, and applies the cement to the roughened surface.

A machine for cutting out boot and shoe soles, invented by J. W. Hatch and Henry Churchill, is illustrated by Figs. 1009, 1010. A is a shaft carrying at its lower end a shoe B, to which a punch C is secured; shaft A is provided with journals which fit in boxes secured to the front of a slide P, which, fitting in vertical guides in the framing of the machine, receives a vertical reciprocating motion from an eccentric pin *p*, Fig. 1010, on the end of a driving-shaft Q.

When shaft A reaches its highest position, a spur-wheel E comes to gear with a toothed segment F′ on the front of a lever F; lever F has its fulcrum in a vertical pin *a*, and, at the time the shaft A is at its highest position, a cam I strikes the rear end of the lever F and moves it round its fulcrum *a* a sufficient distance to cause a spur-wheel E with its shaft A to describe half a revolution.

When the shaft A is about reaching its highest position, the square part of it, *b*, rises above the guide J, and the round part of the shaft *d* comes in contact with the guide, thus permitting the shaft to describe its half revolution.

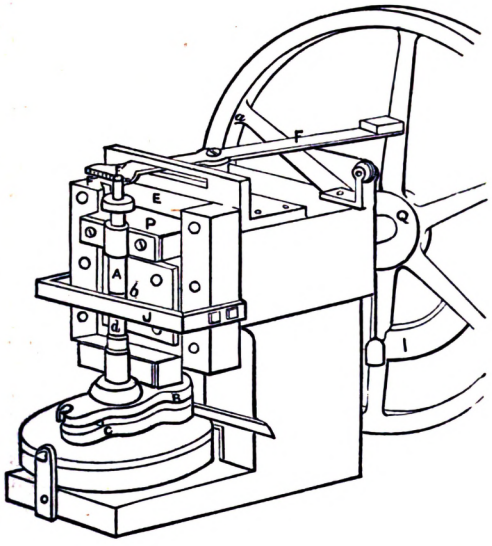
The boot-form introduced by Chilcott and Snell, Figs. 1011 to 1013, has a clamp E, which consists of a strip of sufficient length to reach from the nick at *f* to the top of the front-piece A. This clamp E is prevented from being pulled out laterally by entering a recess *g* in the nick, and is secured at top by a latch *h* catching a pin *i* on the top of clamp E. The inside of the strip is furrowed from end to end, and the recess in which it is received is correspondingly furrowed to hold the material securely. The clamps I, I, fitting to the outside of the front-piece and partly over the clamp E, are attached to screws K K, which fit in female screws in the rod L. This rod L is fastened at its lower end to the bottom part of the front-piece. Its upper end is attached to the front-piece by a plate P in the manner shown in the figures. The plate P is fastened to the front-piece by a screw N, which can be taken out; pins *j j* serve to hold the clamps I, I, in position.

Figs. 1014, 1015, refer to J. and E. Arthur's machine for cutting uppers and soles from sheets of india-rubber. The endless apron B, which has an intermittent motion, receives the sheet of india-rubber *a*; the cloth J between the rubber and apron being properly wetted by its passage through a water-trough F. Two endless chains K carry the die-frames *d* with the heated dies *f*. The die-frames are pivoted to the chains at *g*, and are carried by the chains through the stove M and over the roller D. When over the roller D, the sides of the die-frames come under stationary plates *h*, and are in their onward motion firmly pressed upon the india-rubber, which is thereby drawn over the roller D at the same speed with the dies. The dies cut, or rather melt, through the rubber taking out pieces according to the shape of the dies. The pieces are conducted to the apron G by means of thin fingers (twenty) secured to a swinging frame *r*, whilst the waste still remaining attached to the piece *a* passes over rollers *l* and *m*, and between *m* and *n*, on to the apron *o*. As soon as the die-frame, after having performed the cutting, comes round the chain-roller *b*, the extensions *v* of the frame will strike and pass under the pin *w*, which throws up the front part of the die-frame so as to make room for the die-frame which passes below.

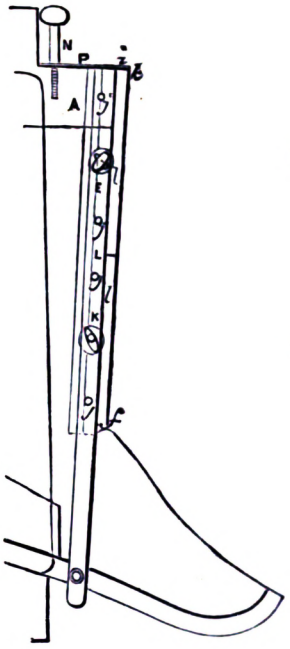
In Mollière's machine for cutting uppers, Fig. 1016, G is the piston of the steam-cylinder operating the bed I. The skins are laid upon the bed I, and the cutters, consisting of pieces of bent steel, placed upon the skins, and then steam-power applied to lift and press the table, skins, and cutters, against the head-block C, so as to cut pieces corresponding to the shape of the cutters.

With Mollière's machine for rasping and dressing heels and soles, Fig. 1017, the operator applies the bottom of the sole first to the tool T, for the purpose of having the rough parts of the leather and the jags of the nails taken off; the sole is then applied to the tool *f*, and the heel to a tool *v*, to finish the dressing. During the whole of the operation the tools are kept turning very rapidly.

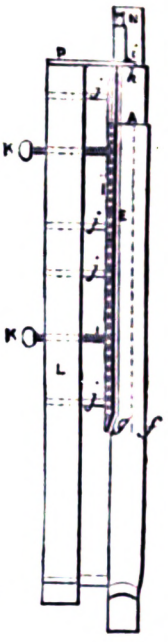
1009.



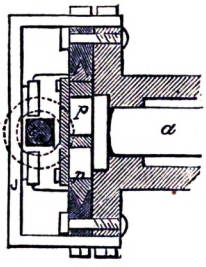

1011.



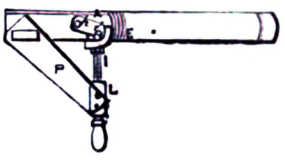

1012.



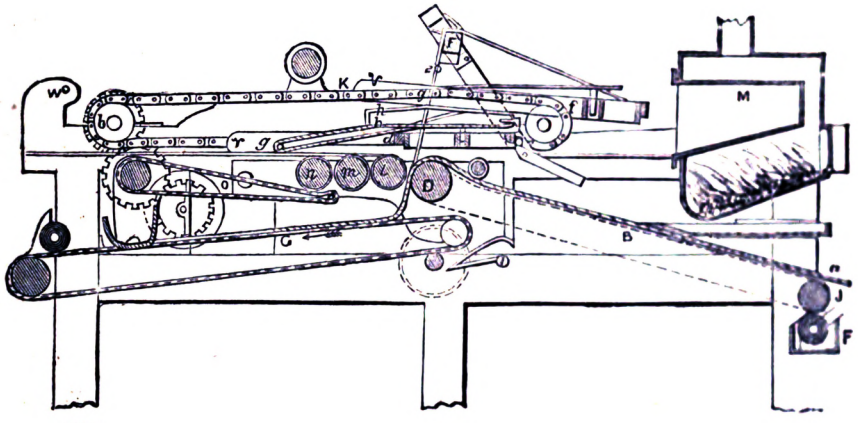

1010.



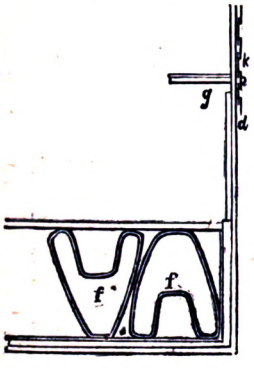

1013



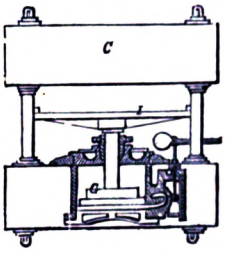

1014.



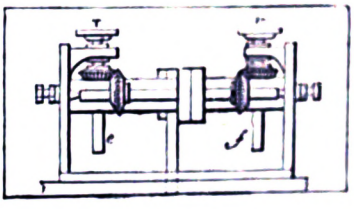

1015.




1016.

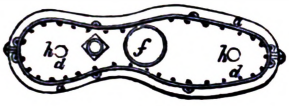



1017.



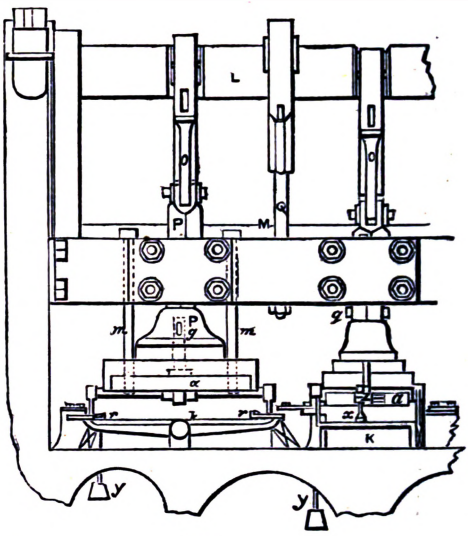
Figs. 1018 to 1023 refer to Mollière's machine for cutting out, punching, and stamping soles. The cutting out, pricking, and stamping, or numbering of the size of the shoe, is done at one blow, by means of punchers *a*, of the shape of the sole and heel, provided with prickers *d*, and stamps *e* and P. *m m* and *o* are the detaching-rods, the rods *m* working through holes *h* in the punching-frames; the punches are operated by eccentrics upon shaft L, which eccentrics are so set that the punches will, one after the other, arrive at their lowest or punching position, so as to distribute more equally power and resistance. When the punchers pass upward, the pieces of leather encounter the rods *m*, which are stationary, and are detached by them from the punches. The rod Q serves as stamp, and also as detaching-rod for the heel-pieces. The workman holds the strip, and puts it under the puncher; but, as this must be done with great rapidity, the leather finds itself guided and stopped in such a way that it can be instantly moved into its place. The guides to effect this consist of two pieces *r*, forming the sides of a square—one of which is graduated, and has on it the numbers of the sizes. As the puncher is always in the centre, these guides must be governed by a single movement in their approach to and retreat from it. This is done by the following mechanism:—Two pieces S slide on a guide-bed, and have an oblique groove, in which plays a pin fixed to the guides *r*; these two pieces S are connected by the cross-tie *t*, and controlled by the screw *u*, which, being attached to a bracket, causes the traverse *t* of the pieces S to move forward or backward, so that the pieces S, by their oblique grooves, push forward the guides. The stopping-piece *x* is supported upon a small axis *v*; it is kept down upon the leather on the flat by the counter-weight *y* attached to the axis, while the puncher is cutting; a spring-catch hitches under the piece *z*, and lifts up the stopper as fast as the puncher rises, which leaves time enough to remove the leather that has been cut; when it gets up as far as it can, the piece *z*, which has described the arc of a circle, lets the catch go; and, being drawn down by the counter-weight *y*, the stopper falls back to its place.

1018.



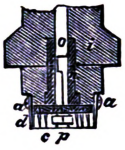
1019.

1022.




1020.

1021.



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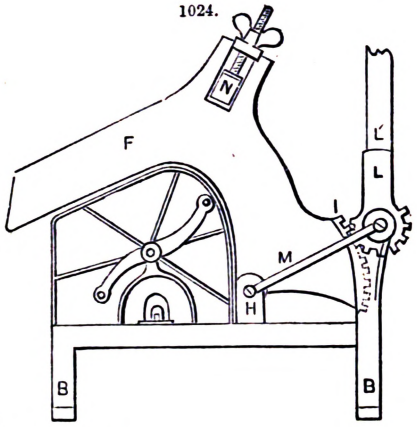
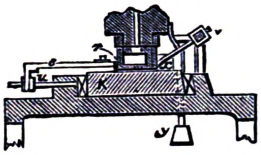



1023.



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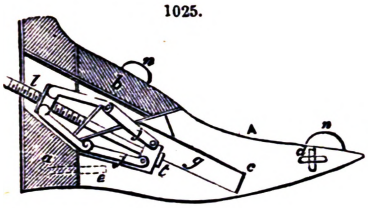
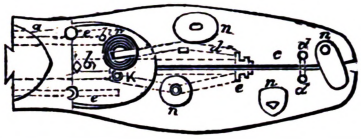
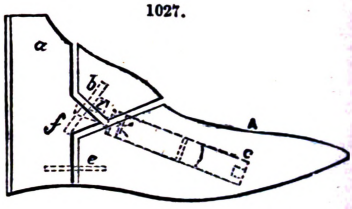


1026.



1027.



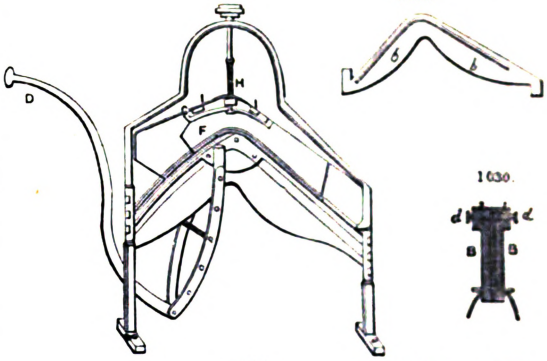
Horace Wing's wrinkling or crimping machine, Fig. 1024, consists of a frame B, upon which is arranged a crimping-plate F, so constructed as to leave its front end unobstructed. It is pivoted at the inner end to a fulcrum-bolt H, and operated by means of a gear-segment L, attached to a lever L', engaging with a corresponding gear-segment I on the outer end of the lower limb M.

Figs. 1025 to 1027 represent Warren Holden's boot and shoe stretcher. If one side of the boot is to be stretched, a knob *n* is attached to one of the parts *e*, and the corresponding side of the boot is properly moistened. The last is then placed within the boot, and the screw *l* is turned, thus forcing apart the sections of the last, and stretching the moistened side of the boot. If the

toe of the boot requires stretching, the link *d* is disconnected by removing the screw *d'*. The turning of the screw *l*, in the position shown by Figs. 1026, 1027, will expand the front ends of the parts. Should the instep require stretching, the levers *j j* are placed in the groove *i*, Fig. 1025, and the levers then expand vertically. When in the groove *g*, the levers are placed horizontally.

Figs. 1028 to 1030 illustrate H. B. Horton's crimping machine. A piece of wet leather having been laid across the jaws, it is, by the raising of them through the lever D, forced upon the crimp-form F; by the repeated sliding up and down of the jaws on the leather, it is thus smoothed, and embraces the crimp-form. Should there be any thin place in the leather, and the wrinkle not perfectly removed, the nearest set screw *d* is turned, and the wire *b b* made to project beyond the face of the jaw opposite the screw. The angle-iron G, clamps I, and screw-rod H, serve to draw tight the leather on the crimp-form.

1028. 1029.

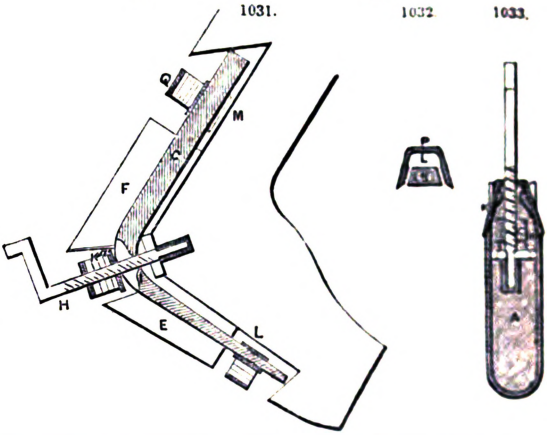



1030.



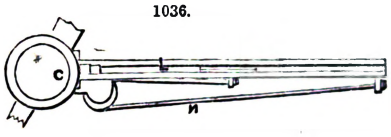

Referring to Figs. 1031 to 1033, which show Daugherty's boot-crimp, the slides L M fit loosely to the arms of the elbow G. The nut I is provided with projections *a a*, which extend up each side of the elbow so as to form two inclined planes which correspond with the inside of the clasp K, which clasp is perforated so as to traverse freely upon the screw H, and the inside of the arms are scored so as to gripe the leather upon the projections *a a* of the nut. The edges of the leather having been inserted between the slides L M and clasps P Q, and between clasp K and nut I, the screw H is turned, by which means the elbow G is moved outward, and with it the clasps, thereby stretching the leather. As the screw is turned, it slips a little on the nut, and slides and draws the clasps on, so that the scored part of the clasps gripes the leather tight. The elbow, and so on, are received in a groove in the crimp-board A, formed by projections E and F.

1031. 1032. 1033.

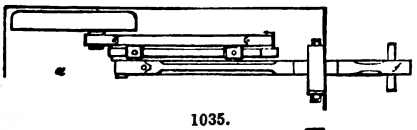



Thompson's machine for polishing the soles of boots or shoes, Figs. 1034, 1035, is of simple construction, having a polisher or polishers *g h*, made of bone or other proper material, attached to a shaft *f*, which has a reciprocating motion imparted to it in any desirable manner.

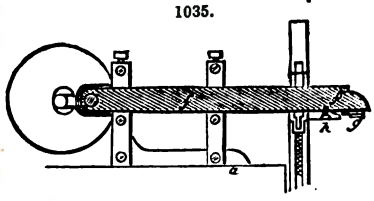
1036.



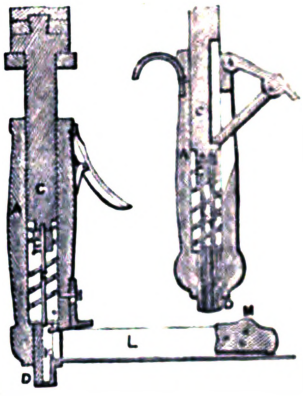

1034.



1035.



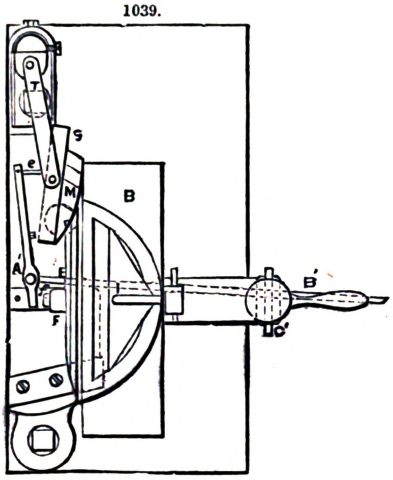
1037. 1038.



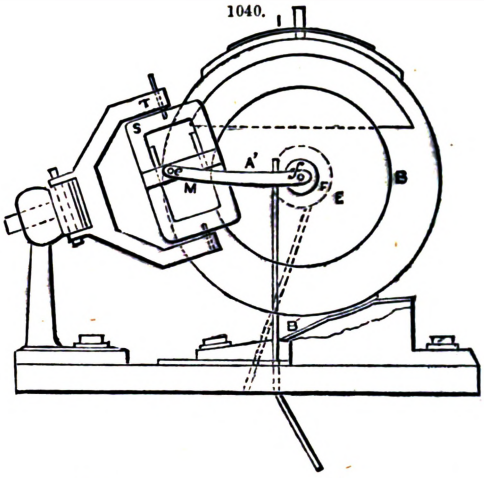

Figs. 1036 to 1038 represent A. Swingle's hand pegging-machine. By striking with a hammer upon the top of an awl-driver C, the spring-slider D is driven up into a handle A, splitting a peg from the block which is arranged in the space L between the said slider and the peg-wood driver M; to the latter is imparted a constant tendency to press the block forward by means of an elastic band N. The awl E and peg-driver F work through holes I and K in the slider, the principal object of the slider being to draw or force the awl out of the leather sole, or other articles, immediately after having been driven into the same. G is an india-rubber spring attached to the lower end of the awl-driver.

Hill's machine for skiving boot and shoe counters is represented, Figs. 1039 to 1041. A lever A′, turning horizontally, has its fulcrum upon the upper end of a lever B′. Studs *e f*, projecting from lever A′, rest respectively against the middle of the rocker-frame S and the end of shaft F. B′ turns upon a fulcrum at *g*, and is operated by a foot-treadle below. By means of the levers A′ B′, the clamp-plate E and the rocker-frame S are simultaneously moved towards the rotary bed B; the clamp-plate being carried into contact with the leather to be skived, while the knife is borne against the thin edge of the clamp-plate and against the edge of the rotary cylinder, so that, whatever may be the thickness of the piece of leather, the knife will be made to adapt itself to that thickness. At the same time that the face-clamp is moved towards the cylinder-bed, the peripheral clamp will also be borne down upon a counter placed on the periphery of the cylinder and between the same and the clamp.

1039.




1040.

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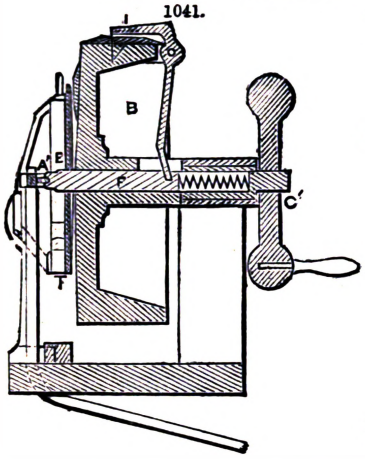


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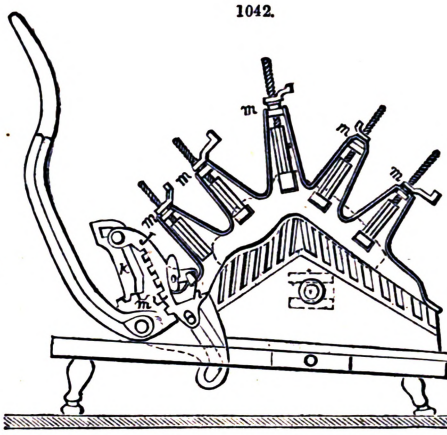


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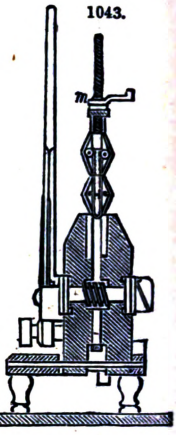
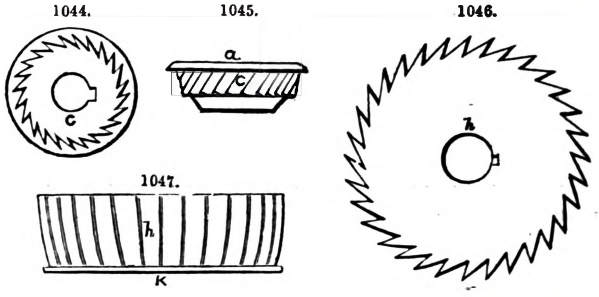



Figs. 1042, 1043, show Zeigler's boot-crimping machines. The jaws are corrugated, so as to work the leather away from the angle of the crimping-iron and into the foot and leg of the boot. The nuts *m* serve to stretch the leather upon the crimping-iron. The slots in the plate K are so constructed as, in combination with the segment-gear M and rack J, to move the foot of the crimping-iron into or between the jaws twice as fast as they move the leg, and to give the foot a compound motion which, in combination with the corrugations in the jaws, works the leather in the required direction to crimp it properly.

1044. 1045. 1046.



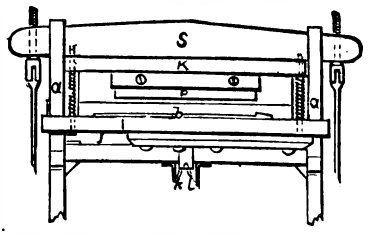

1047.




J. P. Mollière's machine for cutting the edges of boot and shoe soles is referred to in Figs. 1044 to 1047. This plan consists in arranging two revolving tools G and *h*, both of the same construction, only *h* being of larger size than G. The side of the shoe is first held against tool G, placing the edge of the guard-plate *a* between the upper and the sole. The shoe being thus slipped along to the point, and the same way with the other side of the shoe, the edge of the sole is finished with the exception of the heel. The heel is cut by the larger tool *h*, it being provided with a similar guard-plate K, in the same manner as the sole.

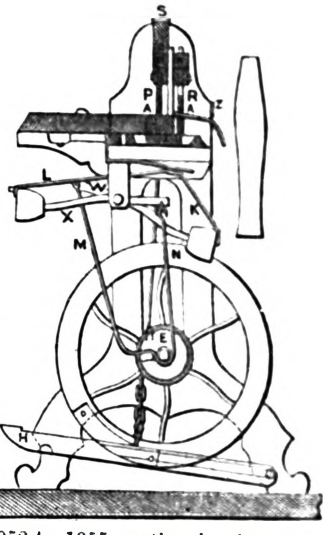
In working Griffin's machine for cutting out soles, Figs. 1048 to 1051, the operator places his foot on treadle H and moves it up and down, so as to impart to the shaft c a reciprocating rotary

1048.




1049.

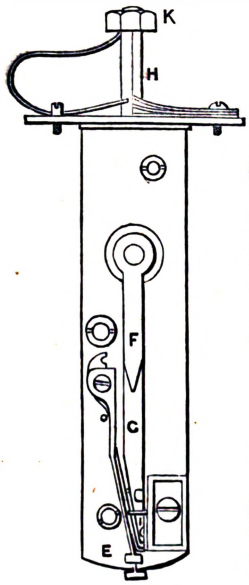
1050. 1051.




motion, he at the same time holding a strip of leather on the top surface of the table, and against a guide-bar *z*. After each cut, he moves the strip forward against the guide or stop bar. The carriage I has an intermittent reciprocating motion imparted to it, which carries each of the knife-bars K K in succession directly underneath the depressor-bar S, which, descending thereupon, forces the knife-bar and its knife P or R downward towards the cutter-block, and cuts through the leather. Fig. 1051 represents the soles as cut out by the machine. Each knife is elevated from the leather by the springs *a* on the rods that guide its bar K.

In R. H. Thompson's hand machines for pegging, Figs. 1052 to 1055, motion is given to a slide H by striking upon head K. The slide H carries the awl and peg-driver. The peg-driver is intended to drive one peg at the same time that the awl makes the hole for the next peg, the machine being moved the distance from one to the next by a slight pressure of the hand

1052.

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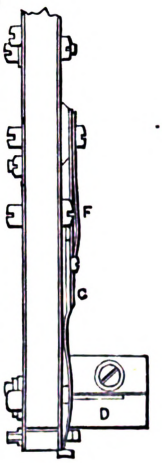


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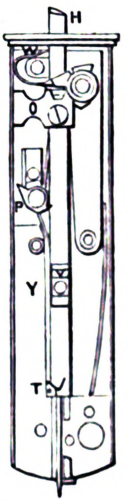


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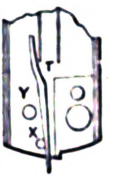



in that direction, this distance being measured, and this motion of the machine restricted to correspond, by the spring-spacer T. The point at the lower end of T, being held down by spring W, pierces the leather sufficiently to keep the machine from being easily moved out of place if a slight downward pressure is exerted upon the machine. Just as the slider H completes its descent, the arm O on the slider operates the tumbler P, the latter taking into a notch in the spacer T, and thus withdrawing the spacer from the leather at the time the awl is sunk deepest into it. T has also a slight vibratory motion in a groove in the spacer-plate Y, limited in one direction by the side of the groove, and in the opposite direction by the eccentric adjusting-pin X, by the turning of which the travel of the spacer may be accurately graduated. The spacer bears against this pin; the pressure of the hand in the direction the machine is to move, will, however, move the spacer to the opposite side of the groove; then, as it is raised by each descent of the awl and peg-driver, it will spring forward against pin X, and, as the awl begins to rise, will descend in the same position upon the leather; and when the awl rises so as to clear the leather, the pressure of the hand in that direction overcomes the spring of the spacer, and moves forward the machine for the next peg. The peg-wood is placed between the part G of the feeder and the spring D. This spring-feeder is operated by the head of the screw V, which holds the awl and peg-driver to

the lower end of the slider, and which projects through a slot in the front of the case, striking, as it descends, against a bend in the feeder, and pushing it back so as to give it new hold upon the peg-wood, at the time the wood is held firmly by the cutters and a clamp E.

With Rice and Whorf's apparatus for lasting and applying soles to shoes, Figs. 1056 to 1058, the sole and the upper are first placed together upon a last A, the upper being made to overlap the outer surface of the in-sole, and affixed by cement. The whole being thus prepared, it is next placed within the clamping-bed B, and the parts of the latter closed. The platen of the press is depressed, to carry the punches on the under-side of die *w* into contact with the parts of the upper which overlap the inner sole, so as to make perforations through them, and either into or through the inner sole. The platen C is then elevated, and cement applied to the outer surface of the inner sole and overlapping parts of the upper. The outer sole is laid upon the cemented surfaces, and the slide G moved so as to bring the die *u* directly over the last A. Next, the platen is to be forced down upon the outer sole, so as to press it closely in contact with the shoe, and expel from between the soles the superfluous cement.

Dinsmoor and Bartlett's instrument for chamfering the edges of shoe-soles is referred to, Figs. 1059 to 1061. The piece of leather is laid upon a flat table, and the blade A and spring-presser H are borne down simultaneously upon the leather, while the end of the lever-gauge G turning upon fulcrum *d* is made to rest upon the table. This done, the cutting-edge *a* of the tool is maintained at such an angle from the table as occasion may require, and the tool is pushed forward upon and around that portion of the leather which is to be chamfered. The frame B is fastened to the knife by means of a wedge *a*.

Figs. 1062 to 1064 show J. W. Hatch's machine for cutting out soles. The cutter is attached to a vertical shaft, which is provided with journals to work in bearings in a slide P, moving in vertical guides in a framing C, and receives its vertical reciprocating motion from eccentric pin *a*, at the end of the horizontal shaft D. The shaft in this machine makes only about three-fourths of a revolution in opposite directions alternately, movement being produced by a treadle F, which is a lever of the first order, with its fulcrum *g* at the rear end, secured to the floor or to a suitable bed-plate; the treadle being connected by a rod *o* with a wrist *b*, at the back of the fly-wheel G of the shaft D.

While the machine is at rest, the wrist is always held in one of these two positions by a weight *r* attached to or cast on the fly-wheel, the weight *r* resting upon one of two fixed standards *f f*. In either of these conditions of the wheel and wrist, the treadle is of course raised. The operator stands in front of the machine, in a convenient position for placing the pieces of leather or other material in a proper manner upon the table H for the action of the cutter; and when he depresses the treadle by his foot, he moves the wheel far enough to bring the weight *r* over the centre of the shaft D; but the momentum the weight has acquired in moving to that point carries it past the centre, and then the pressure of the foot being taken from the treadle, it descends by the force of gravity until it reaches the other standard, thus completing the movement of the wheel. This movement of the wheel brings down the cutter and raises it again, and, just before its termination, it moves the lever E to reverse the position of the cutter by the action of one of two projections *d d* upon one of the prongs *e e* of a fork on the rear end of the lever. The prongs *e e* of the fork are at different elevations, and the projections *d d* at different distances from the shaft D, to correspond with the elevation of the prongs *e e*; so that when the wheel moves in the direction of the full arrow shown in Fig. 1062, the projection *d* may pass under the higher prong *e* and strike the lower prong *e*, thus throwing the lever to the position shown in Fig. 1063; but when the wheel moves in the direction of the dotted arrow, the projection *d* may pass over the lower prong *e* and strike the higher prong *e*, thus throwing the lever to the position the reverse of that shown in Fig. 1063. The movement thus given to the lever takes place just before the weight comes in contact with the standards *f f*, and is just sufficient to give half a revolution to the punch-shaft. To keep the cutter-shaft from turning back too soon, the friction of a bar *h* is applied in a yoke I; on the top of the framing, between the top of the yoke I and the bar *h*, the lever E works snugly, and the bar is forced up against the lever to produce the necessary friction by two india-rubber springs *i i*, one at each end. Stop-screws *j j* are also applied to the yoke I, to stop and regulate the movement of the lever.

Polishing or burnishing the edges of heels and soles with Mollière's machine, Fig. 1065, is performed in the following manner:—The steam passes from the *boiler* through a pipe *x* and into branch pipes *x*, one for each burnishing-tool *p*, and can be let into the hollow shaft *l* and the chamber *p* within the tool *p*, by opening the cock *u*. A number of these tools of slightly varying sizes are arranged in line, and each tool kept rapidly revolving. The polishing is effected by presenting the edge of the sole or heel to the revolving polishing-tool and pressing it gently upon it.

Mollière's arrangement for mounting uppers on lasts is shown in Figs. 1066, 1067. It consists of an adjustable frame I and a thumb-screw G, armed with its tooth-clamp H, which, pressing vertically upon the inner portion only of the heel, holds the *last* securely in its position, and gives free access to the parts of the last on which any work is to be done by the apparatus.

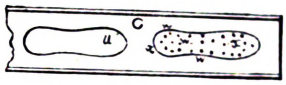
Jackson's machine for cutting out uppers, Fig. 1068, consists of a frame A, to which is attached a cross-head E; this cross-head is raised and lowered by the action of the shaft in the centre, the wheels I and the levers G. The leather is fed in at D on the platen B; the cutters being fixed to the cross-head, and guided in their descent by the indicators T, T.

Fig. 1069 represents Ellison's boot-holder, which consists of a curved arm A reaching from the sole of the foot to the top of the leg L, where it is fixed. This is used in combination with the lever B provided with a last-shaped foot, a handle K and a ratchet C to operate with a pawl D.

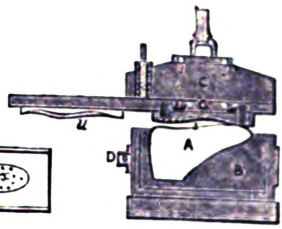
Fig. 1070 shows E. M. Dickinson's machine for holding uppers. It consists of a forked clamp B, arranged on the frame A, and hinged at one end. It is operated by the lever C working the rod *d*, the yoke *k*, and the springs *J*, *i*.

1056.

1057.




1058.

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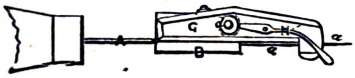

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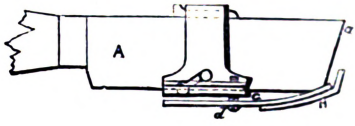


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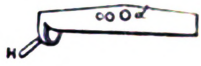

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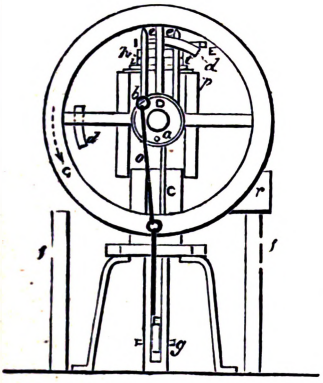

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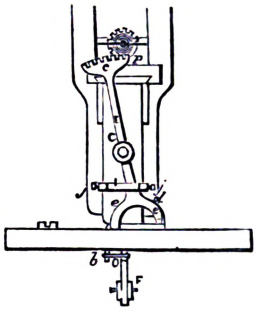

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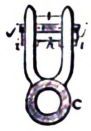


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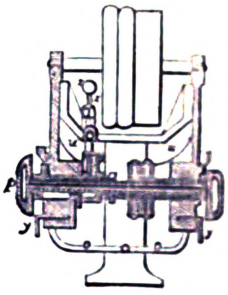
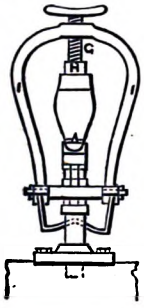


1066.



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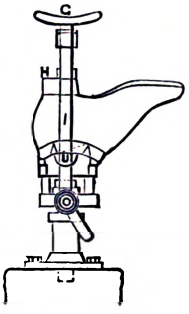
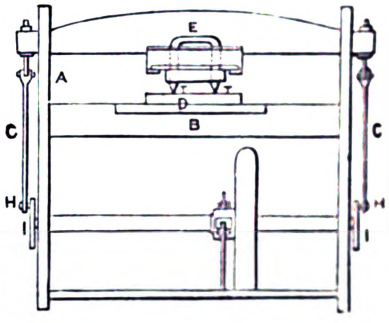



1068.

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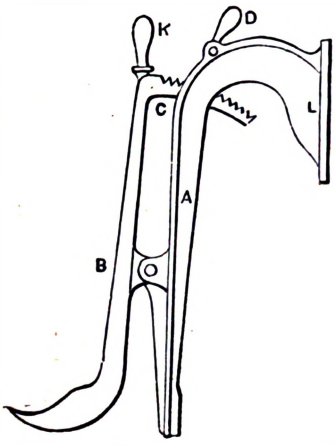


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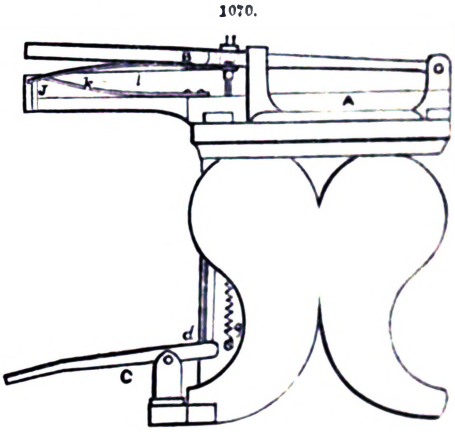
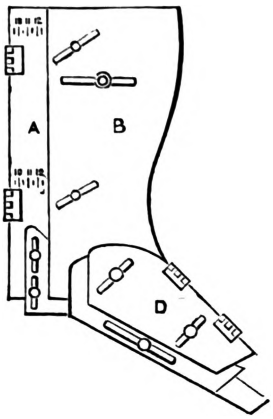
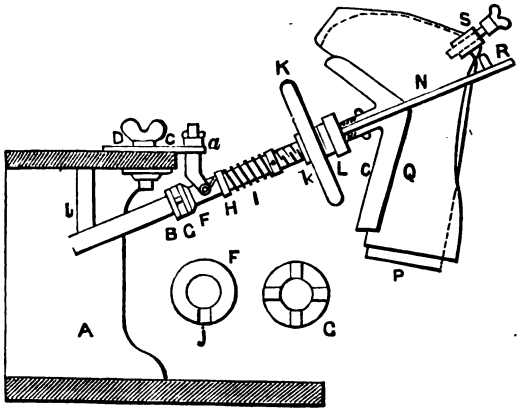


Drew's pattern for cutting boots, Fig. 1071, consists of two pieces of sheet metal A, B, of rectangular form, connected together by hinges; and two other pieces of the same material attached to the former in such a manner as to be capable of being adjusted laterally, one of the over-pieces D having a foot portion provided with a wing connected to it by means of hinges.

1071.



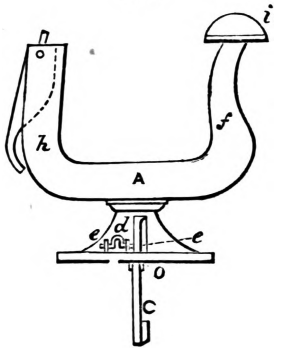

1072.




The apparatus, designed by O. J. Warren, for crimping, Fig. 1072, is applied to the bench by a swivel process, which permits the whole to be turned to the right or left as the work proceeds. The curved bar G, which supports the form P, upon which the leather is crimped, has its groove lined with india-rubber Q, which prevents the wrinkling of the leather while undergoing the stretching process. A spiral spring is employed to hold together the two parts of the clutch or yoke N, R, and thus retain the work rigidly in any position; but at the same time adapts the clutch to be disengaged to allow the shaft to be turned to bring the work into convenient positions for the operator. The nut K on the screw *k* of shaft B is connected with the yoke N through the medium of the collar L, so as to allow the yoke to be turned independently of the nut. F is a sleeve on shaft B, provided with a projection *j*, and is used in combination with the notched hub G, the collar H, and the spring I. The coupling by which the shaft B is attached to the bench is composed of a plate C, secured to the bench by a screw D, and provided with a socket *a* to receive a pintle of a fork which is fastened to the sleeve F by pivots.

Gustins' movable jack for boot-making is shown in Figs. 1073, 1074. The arms *h*, *f*, of the frame A, have supports, as *i*, for the toe and heel of the boot, and admit of rotation on a pivot at A. The bolt C and the friction-washer *o* prevent a too ready and easy movement of the yoke A upon the bolt in a horizontal plane. The crank-stop *d*, sliding in the blocks *e e*, with the holes in the segment C, Fig. 1074, permit the instrument to be inclined for working purposes.

1073.

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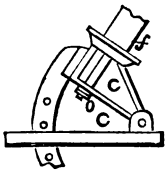
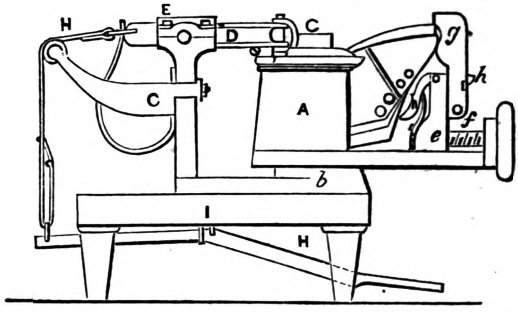



1075.

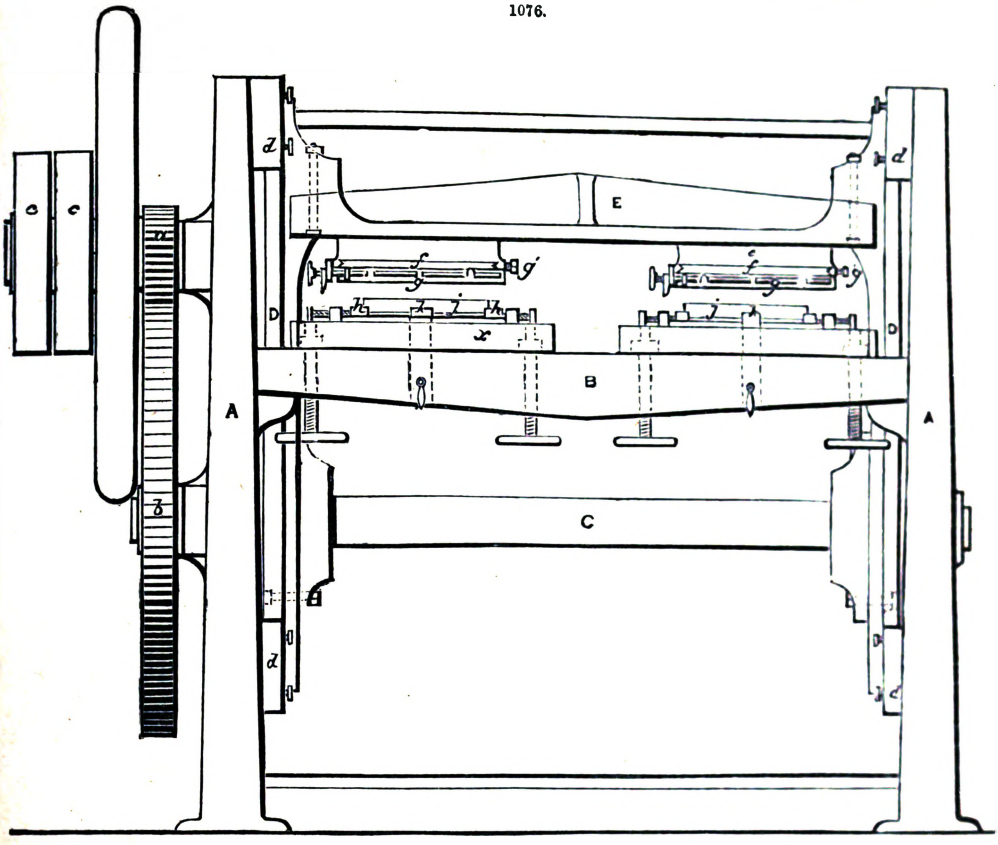



Referring to Fig 1075, which shows J. H. Belser's machine for shaping heels, *g* is a toe-clamp, *h* its latch fastened to a standard *e*, which is provided with an adjusting screw *f*, and attached to a shoe-holder A. The knife C works through a rocker-tube E by means of the slider D, which is adjusted so as to act in combination with the arrangements shown at H and G. The position of the heel whilst being shaped is shown clearly at C.

Fig. 1076 shows a side elevation of a machine for cutting out and pricking soles and heels, by Craven and Carrack, of Leeds. The parts A are standards or framework braced together by the table B; C is a shaft, actuated by pulleys *c* through intermediate wheels *a*, *b*. Cams on the shaft C impart a reciprocating motion to the slides D working in V-grooves *d*. The slides are connected by the cross-head E, to which are secured the frames *e*, which carry the wood blocks and guides *f* and *g*. The wood blocks *f* are bound with a hoop of wrought iron, and are adjusted in any desired position by means of set screws *g* in the V-races of the frames *e*. The guides *g*, provided with set screws, are to prevent the leather from being thrust too far either laterally or longitudinally. On

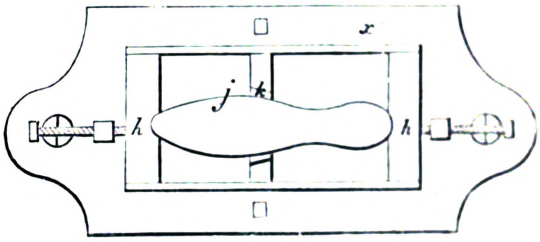
the table B adjustable frames $x$ are placed, which carry the clips $h$. These clips support the knives $j$, and may be adjusted by set screws, according to the size of sole or heel required, having V-edges which slide in the frames $x$. The parts $k\,k$ are two spring-clips to stiffen the knives $j$.

1076.




The prickers are not shown, but simply consist of a framework of pricks or needles, of the same contour and pitch as the required line of nails, fastened to the wood blocks and piercing the leather in their descent. The knife $j$ and its adjustments will be seen more clearly by referring to the detached plan of the framework $x$, Fig. 1077.

1077.




The machine being set in motion, a piece of leather is placed by the attendant over one of the knives, the cross-head descending, the pressure of the wood block cuts the sole or heel required, which drops through the knife and the aperture in frame $x$ and table B into any convenient receptacle.

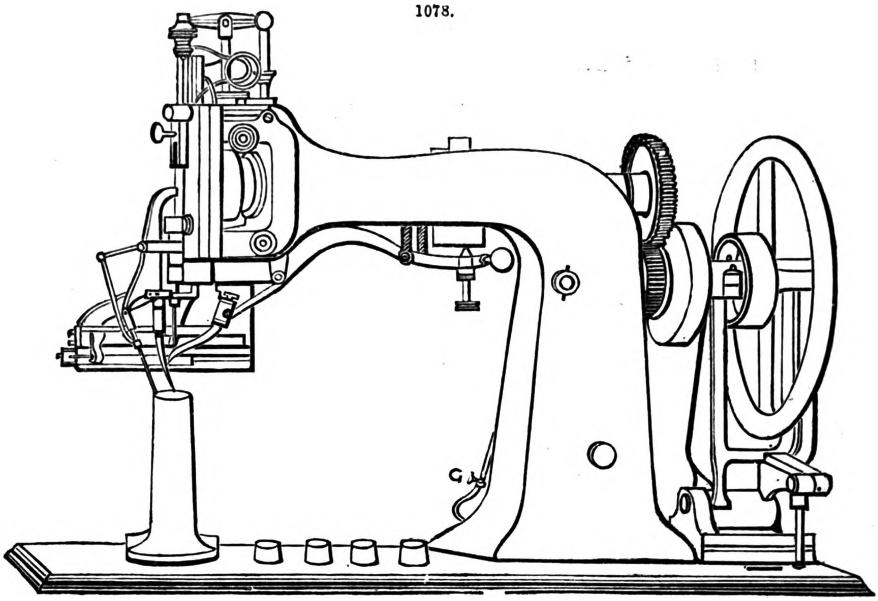
The operation of fastening a sole to an upper was for some time the most difficult portion of boot manufacture by machinery. It has now, however, been greatly simplified by an adaptation of the sewing machine invented by John Keats and W. S. Clark, and termed by them the Crispin Machine.

The leading features of this machine are the combination of a hook and a shuttle, instead of a needle and a shuttle. This arrangement allows of the thread being thoroughly saturated with the wax, which does not get squeezed out, as in passing through the eye of a needle. Further, the hole made in the leather is no larger than the size of the hook, because the hook has no thread in it while piercing the material. Thus, a thicker thread can be used than with the needle. The stitch, which is formed on the surface of the leather, is a twisted lock-stitch, one of the firmest made. The machine is arranged to be driven by steam-power, and the motion can be instantly stopped by a foot-lever at any point of the stitch, so that the workman has the free use of his hands.

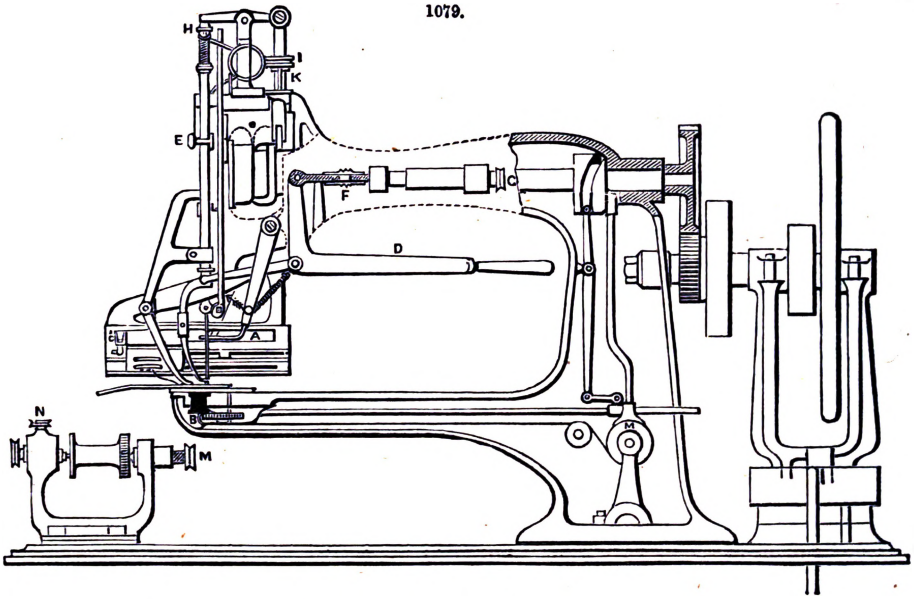
Fig. 1078 is a perspective view of the post Crispin, which is used for welted boot sole sewing. Fig. 1079 shows the arm Crispin, which is employed in heavy work, such as closing heavy uppers, belt-sewing, harness work, and so on. The hook is first fixed by turning the machine by hand until the line cut across the edge of the needle-bar L at the lower end, pointed at by the arrow, is on a level with the bottom end of the slide, and then fixing the hook with its point on a

level with the point of the divider A, care being taken to have the notch which receives the thread at right angles with the arm of the machine. After the large bobbin is charged with thread and placed in position, the cover and hook-plate at the end of the arm are drawn off, and the thread brought over the guide-pulleys until it reaches the pulley B; it is then passed through the eccentric hole in the small gear-wheel. The thread is then drawn forward and passed through the hole in the hook-plate, the cover and plate being replaced. To thread the shuttle, the bobbin has to be placed in it, with the long centre end foremost. The thread is then passed through the upper slot over the bar and through the lower slot, and then through one of the round holes. The operator then places the shuttle upon the slide, and puts down the hinged stop C. He raises the

1078.




1079.

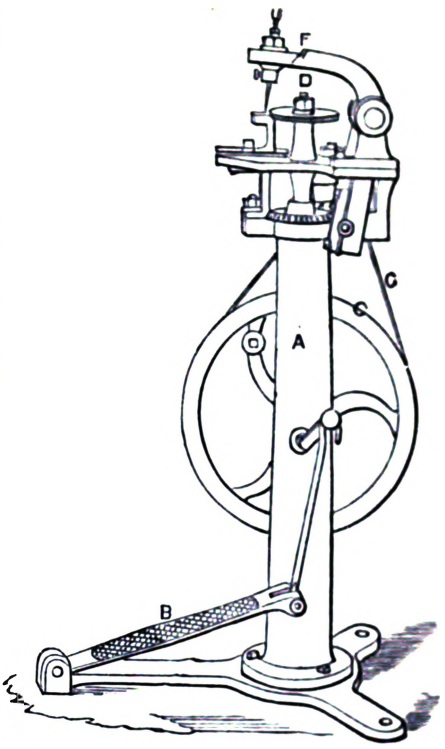



pressure-foot by means of the lever D, and puts the work under the hook so as to be moved from left to right. After the machine is charged with waxed thread, the gas G is turned on, and lighted through the holes in the side of the arm, and also the jets behind the shuttle-race, until the machine is sufficiently warm to make the wax soft, care being taken not to let the flame come in contact with the casting, as this produces soot, which destroys the heating-power of the gas.

A counter-shaft mounted in the frame under the table being put in motion by the driving-belt, the machine is started by pressing the foot-lever, thereby bringing the pulley covered with leather into contact with the internal pulley mounted on the end of the driving-pinion. The moment the pressure with the foot is withdrawn, the machine instantly stops. Suitable tension of hook-thread is obtained by the thumb-screw M. The feeder is adjusted and kept to push in the required

direction by the round vertical bar being pinched with the thumb-screw E; an angle of 45° to the arm is found most convenient. The pressure is adjusted to the thickness of the work by means of the double screw-nut F. The amount of pressure is adjusted by the screw G. The feeder is adjusted to the thickness of the work by turning the screw H. The length of the stitch is regulated by turning the screw I, which is secured by the lock-nut K. To remove the large bobbin, the pin N is taken out; the tension-spring then forces it out.

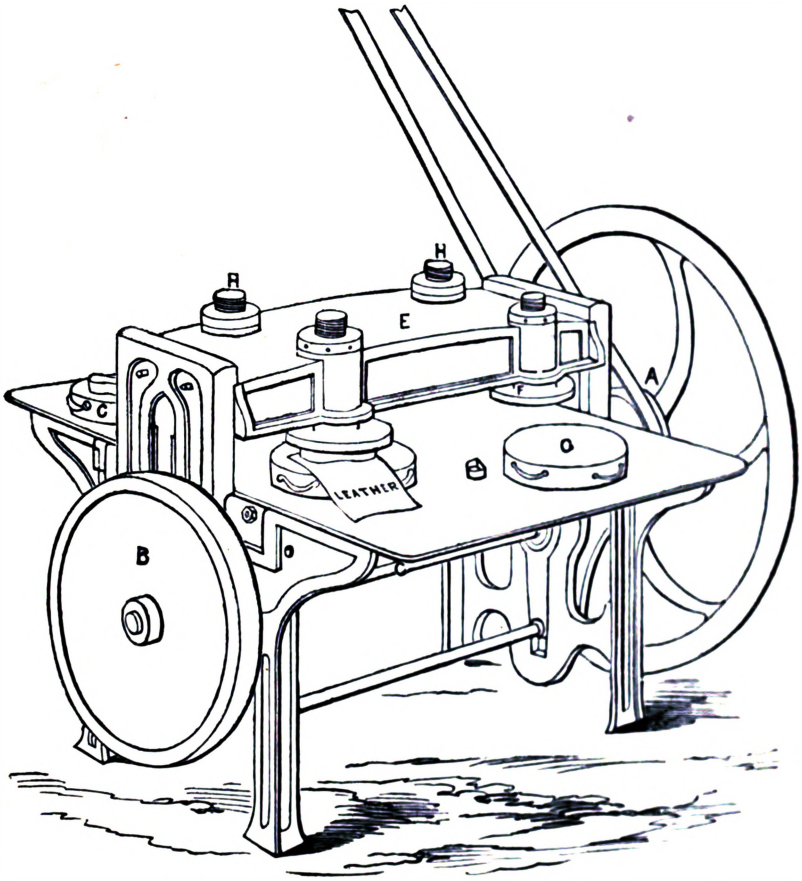
1080.




The Pricking Machine, designed by Gimson and Co., of Leicester, is used for making small holes in the bottom of the soles and heels of boots and shoes to receive the rivets. It is contrived so that the distance the holes are apart can be varied according to the number of rivets required. It consists of a standard A, Fig. 1080, through which is a small crank-spindle; the treadle B is attached to the crank, and the driving-wheel C is fixed at the other end of the crank-spindle; the motion is imparted by a cord G from this wheel to a worm-shaft; the worm gives the upright spindle D a revolving motion, and the crank E gives to the arm F a chopping motion; the boy works the treadle with his foot, and with his hands presses the sole against the guide tooth wheel D; this wheel, revolving slowly, moves the sole the required distance as each prick is made by the arm F.

*Gimson's Eccentric Press.* — This machine, Fig. 1081, is used for cutting up leather, and is constructed for the use of four men; the cross-head E moves upwards and downwards, and receives its motion from the driving-shaft A, which

1081.



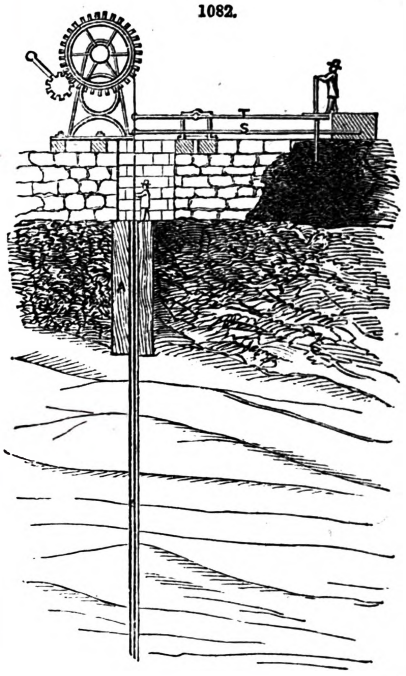
has a pinion attached, and works into the internal toothed wheel B, which wheel is keyed to the eccentric shaft C; the eccentrics are fitted with straps connected to a stretcher—this is fixed to the side D, attached to the cross-head E; the screws H are movable, and can be adjusted by the man to suit the depth of the knife and range of the cutting-tools; wooden blocks G are used to cut upon; the leather is placed on the block, the knife being put on by the man, who also pushes it under the cross-head which comes down upon it and cuts out the sole; the block is then pulled from under the knife, placed on another part of the leather, and the process repeated.

BORING AND BLASTING. Fr., *Action de forer et de faire sauter par une mine*; Ger., *Das Bohren und Sprengen einer Mine in Bergwerken.*

*Boring for Minerals.*—There is but little difference in the system of boring for minerals or boring for water; the kind of rock to be penetrated does not even cause any material difference to be made in the means or tools by which it is done. A hole of 3 in. diameter is in all cases sufficient for a test on a mineral vein. In the U.S. the hemp or manilla rope is used for boring. This is called the Chinese method, because the Chinese have practised boring in that manner since our knowledge of them. The Germans penetrate the rock by means of iron rods, of 1 in. square or more. These rods are screwed together in lengths of 10 or 12 ft. This mode of work causes the operation to be rather expensive, on account of the price of tools and machinery, and it is not very expeditious. The same method was followed by other European nations, and formerly in this country. In recent works of this kind, wooden rods have been used with greater advantage than iron. These rods are long slender poles of pine wood, often 30 and more feet long, mounted with iron and screwed together; they have the advantage of being light and elastic, so as to cause less concussion and consequently less repair than iron rods. Rods offer no advantage over the rope but that of longer durability, and the earth may be penetrated to a greater depth by means of them than by ropes. The latter are limited on account of strength to about 1000 ft., while rods may be driven down to 2000 ft. and deeper. We will describe an apparatus which may be used either for hemp-rope or wire-rope, which was made originally for hoop-iron by the well-known metallurgist, F. Overman, it being cheaper, and served the same purpose as ropes of either kind.

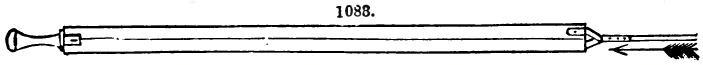
At A, in Fig. 1082, is represented a log of oak wood, which is set perpendicularly so deep in the ground as to penetrate the loose gravel, and pass a little into the rock, so as to stand firm in its place; it is well rammed by gravel, and the ground levelled so that the butt of the log is flush with the surface of the ground, or a few feet below. Through this log, which may be, according to the depth of loose ground, from 5 to 30 ft. long, a vertical hole is bored by an *auger* of a diameter equal to that of the boring in the rock. On the top of the ground, on one side of the hole, is a windlass, whose drum is 5 ft. in diameter, and the cog-wheel which drives it 6 ft.; the pinion on the crank-axle is 6 in. This windlass serves for hoisting the spindle or drill, and is of a large diameter, in order to prevent short bends in the iron, which would soon make it brittle. In all cases where iron, either hoop-iron or wire-rope, is used, the diameter of the drum of the windlass must be sufficiently large to prevent a permanent bend in the iron. On the opposite side of the windlass is a lever of unequal leverage about one-third at the side of the hole, and two-thirds at the opposite side, where it ends in a cross or broad end in case men do the work. The workmen, with one foot on a bench or platform, rest their hands on a railing, and work with the other foot the long end of the lever. In this way the whole weight of the men is made use of, who work with great ease. The lift of the bore-bit is from 10 to 12 in., which causes the men to work the treadle from 20 to 24 in. high. Below the treadle T is a spring-pole S fastened under the platform on which the men stand; the end of this spring-pole is connected by a link to the working-end of the lever, or the hoop-iron directly, and pulls the treadle down. When the bore-spindle is raised by means of the treadle, the spring-pole imparts to it a sudden return, and increases by these means the velocity of the bit, and consequently that of the stroke downwards.

1082.




The spindle is represented in Fig. 1083, a piece of square cast iron, or wrought iron, of from 200 to 300 lbs. weight for a hole of 3 in. diameter. For larger holes, of 5 or 6 in. diameter, its weight must be increased to 800 or 1000 lbs. At one end of the spindle the hoop-iron or rope is permanently fastened by screws or rivets; at the other end the bore-bit is inserted in a round hole and fastened by a flat key. The spindle may be provided at each end with a head, in the

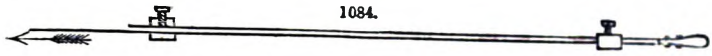
1083.



form of a cross, but these are unnecessary appendages; a simple square rod of iron, whose diagonal section is equal to the diameter of the hole, is all-sufficient for the purpose. The lengths or parts of the hoop-iron may be made as great as possible, and should be of the best fibrous charcoal iron;

puddled iron, even if fibrous, soon gets brittle in the course of time and work. For a spindle of 300 lbs., hoop-iron of 2 in. by $\frac{1}{12}$ is sufficiently strong; for heavier spindles it may be somewhat stronger. The ends of the hoops are fastened together by means of small rivets and drilled holes, and this riveting ought to be renewed at least every two months, because the repeated vibrations cause the iron to get brittle, which is the case at the joints more than in the run of the iron. At the upper end, where the hoop is fastened to the lever, there is a length of hoop-iron nearly equal to one length or part, at one end of which is an eye permanently fastened; this fits in a hook at the lever, and also in a hook at the drum. This loose part of the strap is fastened to it by means of pinch screws, as shown in Fig. 1084; by this means the hoop may be made longer and shorter, as

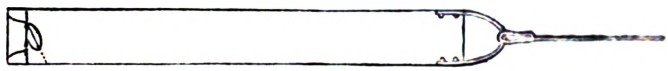
1084.



the bottom of the bore sinks down; the letting out, of course, can be performed only while the work is stopped. If we want to let out while the treadle is in motion, which is necessary in soft rock, a screw about 1 ft. long is provided at the end of the treadle, which may be turned while the machine is in operation. The bore-bit has been shown in Fig. 1083 as it is fastened to the spindle. This is a simple, flat chisel, whose edge is steeled with good cast steel, and a little rounded, so as to play always in the centre of the hole. If the chisel is too round, or pointed in the middle, the hole is liable to get narrow in the bottom; if the edge is straight, the hole generally widens with its depth. Other forms of the bit are of little use, they merely cause trouble and loss of time. The bit must be fastened very firmly in the spindle, and the shoulder of it fit closely to it, or both are liable to get out of order. When the spindle is to be lifted from the pit, the end of the hoop is taken from the treadle and hitched to the drum, which is set in motion. The hoop must be prevented from winding over the hook's eye, or the pinch screws, for that would cause short bends in the iron, and permanently injure it. The drum must be so high above the hole that the spindle may be lifted entirely above the bore-log. For these reasons the upper end of the latter is frequently found to be some feet below the surface of the ground.

The operation of boring is simple; when the hole through the bore-log is sunk, the spindle is let down, hitched to the treadle, and the latter set in motion, which labour two or three strong men can readily perform. If but 10 or 12 inches lift is imparted to the bit, from 30 to 40 strokes may be made in one minute. If a good hop-pole is appended, from 30 to 45 strokes may be made by men, and from 80 to 100 by a steam-engine. The rock is thus penetrated by repeated blows, of which from 50 to 100 are sufficient to sink 1 in. deep in soft slate and shale; from 500 to 1000 in sandstone rock, and from 10,000 to 20,000 strokes in graywacke or gneiss. Even as many as 30,000 and 40,000 blows have been struck to penetrate 1 in. deep in hard graywacke. Iron pyrites are almost impenetrable; and the best plan is, if the vein is but a few inches thick, to break it by heavy strokes of a blunt steel point, directed so as to break off pieces from the mineral. When a certain depth, say 1 ft., or 2 ft., is penetrated, the *débris* of rock, ground into dust, and floating as fine sand in the water of the hole, must be removed, which is done by the pump; this instrument is represented in Fig. 1085; it is a sheet-iron cylinder, of from 3 to 4 ft. long, and $\frac{1}{4}$ or $\frac{1}{2}$ in.

1085.



smaller in diameter than the diameter of the hole, so that it may pass down easily; it is provided at its bottom with a strong iron ring riveted firmly, and soldered to the sheet iron; upon this ring is fitted a valve, which may be a poppet-valve, or a ball, or, what is equally as good as any, a trap-valve formed of a piece of sole-leather or strong india-rubber, provided with a piece of metal to make it heavy and shut close. Metal valves do not shut well, for often coarse sand gets into the pump, which does admit of a hard valve to shut, while a light valve of soft matter will press the sand out, or at least close sufficiently tight to prevent the mud from flowing out. This bucket is gently let down upon the bottom of the well by means of a small rope, a wire-rope, or a hoop-iron tape; it is then rapidly moved up and down a few times by hand, and raised. This latter operation is best performed by a small windlass, erected purposely for the pump. The strong windlass is too heavy and slow for this operation. When the pumping has been repeated two or three times, we may suppose at least all the heavy sand is removed from the bottom of the well. Pumping ought to be performed after the water has been for a while at rest, early in the morning or after meal times. This operation is very simple and effectual. The pump in being raised rapidly from the bottom of the well causes a strong current of water to pass vertically down; this stirs all the heavy sand in the bottom, and even pieces of iron and steel which may accidentally fall into the well, and brings them into the pump. Many other devices have been proposed for this purpose, but we know of nothing superior to this simple machine. See ARTESIAN WELLS.

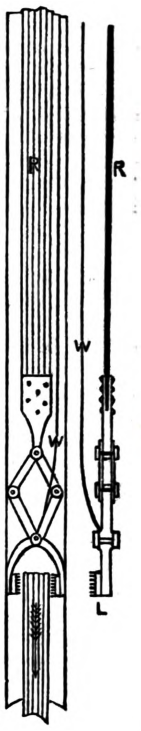
Where a steam-engine is at command, as is generally the case at salt-wells, the operation may be performed with ease, and cheaply. Is a water-wheel or a mill at the place where a hole is to be sunk, the expenses are very small, one man attending the whole operation. In most cases it does not make much difference where the hole is driven down, if not too far off from the outcrop, so as not to miss the ore deposit. If the extent of a mass or vein is known, and we want merely to know the depth from a certain point, in order to calculate the expenses of a shaft before we sink it, it may be profitable to erect a steam-engine for boring, in case the depth is considerable. Horses or mules may be also employed at a common horse-whim to do the work; this, however, is not much cheaper than manual labour, but the work may be done faster. In case a steam-engine, water-wheel, or horse-power is used, a shaft with *cams* or *tappets* must be provided, which latter press upon the treadle instead of the feet of men. If in this arrangement the shaft with tappets

can be so arranged as to be moved farther off, or closer to the treadle, it is recommended; for if changing stratified rock is met with, different heights of stroke or change of lift is required; soft rock or slate cannot bear as strong blows as hard rock. In this case the spring-pole must be strong enough to balance the whole weight of spindle, and rope or iron belt, so as to keep it suspended when at rest. The large drum for winding up the rope may serve as an axle for tappets; the latter are then fastened to the large cog-wheel, and lift the treadle directly, or, what is the same, the end of the rope or iron belt. The crank-shaft, on which the handles are, serves in this case as a driving-shaft, driven by pulleys and belt from the engine, the water-wheel, or horse-power.

*Turning the spindle*, or bit, is a necessary operation which is much favoured by a hemp-rope, not so much by a wire-rope, not at all by hoop-iron, or by rigid bars of iron or wood. In striking the bottom of the well by the sharp chisel, it is to turn around the axis of the spindle, or its own axis, in order to cut a round hole; the more rapid this operation is performed, the more correct is the work, and the faster it proceeds. The hemp-rope, in lifting the spindle, is stretched, and endeavours to untwist, setting the spindle in a rotary motion, in which it continues until its return to the bottom of the well. At the head of the spindle there is a loose eye, or swivel, in which the rope is fastened: the rope will return, when slackened, and assume its twist again. This operation, however destructive to the rope, performs the rotary motion of the bit more perfectly than any other means. The rigid rod, and the hoop-iron or wire-rope, must be turned by hand, if no machinery is expressly prepared for the purpose. If turned by hand, which is done by means of a cross-handle above the bore-log by a small boy, it ought to be done rapidly; each stroke ought to have more or less than a whole revolution. If this operation is not properly attended to, the bit is very apt to cut rifles or flutes, particularly in stratified rock, which are very troublesome in the progress of the work.

*Accidents.*—It may happen that the belt, rope, or the rod breaks, or the bit or spindle is injured, and leaves parts of steel and iron in the hole. If the latter is the case, and the pieces broken off are not too large, the most expeditious plan is, to take a dull hard bit and pound the iron into such small pieces as may be removed by the pump. Is the belt or rod broken, the operation is not difficult, but in the latter case tedious. The hoop-iron, or a hemp or wire rope, is easily drawn up, which is most conveniently done by the following machine. In Fig. 1086 is represented a pair of tongs, which are fastened to the main rope R, which is slackened in letting down the tongs. W is a single wire, or a small hemp-rope, such as a bed-cord, or the pump-rope. When the tongs are so far down as to be below the broken end of the rope, the wire W is pulled so as to open the tongs, after which the belt R is turned round its axis. The lips L of the tongs, forming a basket, sweep now the circumference of the hole, and draw the broken rod into their grasp; when such indications are perceived at the upper end where the workman is turning the belt R, the wire W is suddenly slacked, and the sharp steel lips will bite the iron or hemp; the whole is now lifted by the windlass, and the broken ends mended. With a wrought-iron spindle, hardly anything can happen; a cast-iron spindle may break; but if made of a square form, there is so much room on the four flat sides as to admit two sharp-pointed bits of the tongs, which may fasten in it sufficiently so as to lift it. More vexatious than such breaks is the crumbling of rocks, particularly if these rocks are hard or tough. If the spindle has a little space at its upper end, and a piece of rock falls down from a higher place and wedges in between the spindle and the walls of the well, it causes often long delay and much labour to remove such small stones. Is the treadle moved by men, such impediments are generally observed before the rope breaks, and may be made less disturbing when attended to in proper time; but if a steam-engine or other power is at work, it will tear the rope or rod, and cause the spindle to be tightly wedged. In order to prevent the breaking of the rope, that part of the lifter where the rod is suspended must be made so weak, that, when the cam lifts it, and it is heavier than the weight of rope, spindle, and bit, it will break and prevent by its rupture the breaking of the rope. Is the latter not injured, there is generally not much difficulty in getting the spindle out. At the top of the bore-hole must be always a certain mark, which indicates exactly the depth of the well by the length of the rope; if the spindle is in any way raised above the bottom, we may know it by this mark, or by the position of the treadle. In this case, gentle up and down motions at the rope will generally loosen the spindle so as to make it play; its going down to the bottom, however, ought to be prevented, for which reason the end of the rope is laid on the windlass, and the rope so far stretched as to prevent its sinking to the bottom. By means of the treadle or by hand, the apparatus is now kept in motion and gently raised by the windlass. If these means will not succeed, force at the windlass is tried, but never beyond the strength of the rope so as to break it. If this also fails to lift the spindle, an iron rod, with a blunt end, which cannot penetrate between the spindle and the walls of the hole, is let down by means of the pump-rope, and gentle blows are imparted on the head of the spindle: this will either start the spindle, or will crush the pebbles which hold it. Is the rope or rod broken, these operations must be performed with more caution, so as to prevent forcible lifting; for when the tongs have hold of the broken end of the belt, that is never so firm as the rope or belt itself.

1086.




Most of the accidents are caused by loose stones, gravel or pebbles, crystals or pieces of slate, from cavities above. Most of the rocks contain caves, or nests of crystalline loose matter, which is thrown down by the motion of the water and the vibrations of the boring instruments. In these cases, pipes of sheet iron, of copper, or of other metals, have been inserted in such places;

which operation, however, is expensive, tedious, and not quite safe; much ingenuity has been expended on inserting such pipes. In all cases of boring, the mouth of the well, or upper part, ought to be well secured by the bore-log; it should reach down into the solid rock, and prevent any dropping of gravel from above. When, in the course of the descent, cavities are penetrated which prove to be filled with loose matter, threatening to obstruct the progress of the operation, the best plan is to cut through such a cavern, if possible, and reach the solid rock again. If this cannot be accomplished, the chisel is driven down as far as possible, and the cavity filled by cement, which is closely rammed in by a plunger The cement for this purpose is mortar cement, also called Roman cement, which is made of impure limestone, such as is found in the coal regions and marl beds, in the form of lumps imbedded in marl, clay, or shale. This kind of limestone, when burned, does not slack; it must be ground fine, and is then mixed with water to a stiff mortar. If no such impure limestone can be obtained, common lime is mixed with burnt and finely-ground iron ore, burnt marl, or burnt ferruginous shale, pumice-stone, or any kind of volcanic porous rock. The whole, lime and admixture, of which latter about 40 per cent. of the lime is used, is ground together and mixed with water so as to form a stiff mortar. Cement mortar will harden in the course of a few days under water; but it is advisable to make a trial of it before it is put down into the well. This mortar is filled in canvas or muslin bags, of such a size as to sink gently down to the bottom of the well. A number of filled bags is let down, and then the plunger,—which may be the spindle,—is pressed upon them to break the bags, and drive the mortar into the cavity. This is gradually filled entirely with mortar, and then left at rest for some days. Part of the mortar is, in the meantime, immersed in water, above ground, in order to observe its progress of hardening. When the mortar is hardened below, it is penetrated by the bit, and a round hole bored through it, which forms now a pipe of cement, which will effectually prevent sand or gravel from running down and causing disturbances in the operations.

In all cases of sinking a well or a bore-hole, the progress of the work should be recorded in a journal from day to day; and each day, or at each pumping, a part of the bore-meal, or the coarsest *débris*, saved for future examination. The latter operation is simple, and causes no loss of time. When the pump is raised, the contents of it are cast into a fine wire sieve, or into a bag of fine wire gauze, which is made to contain all the contents of the pump. The water and the fine parts of rocky matter will pass through the meshes of the sieve and float off, while the coarser parts remain. A part of the sediment is saved in a paper, or in a small box, and it is marked with the time and depth, when and where obtained, for future reference. These evidences, when put together, form the elements of a section of the rock strata penetrated by the well, in that particular spot, and are suitable objects for publication. Any geologist can form, by these means, a profile of the rock, or general formation. Many hundreds of *artesian wells* are now sunk, and have been sunk in times past in our country; these would furnish means for obtaining a correct insight of the geology of those places where the operations are performed. For the want of such records, the information arising from the labour of boring, at a particular spot, is lost to the community and the science of geology.

Any size of hole will answer the purpose of the miner; and if 2 in. in diameter could be sunk, it would be sufficiently wide; but this cannot be done; the form of the tools, pump, and rope, require at least 2·5 in. All complicated tools, such as cross-chisels, rasps for widening, and similar instruments, are to be avoided. They are expensive, both in first cost, repair, and cause loss of time. The simple flat chisel will form a perfectly round hole; when attended to in turning the rope, it will make the hole wide enough all the way down; if frequently changed and sharpened, it works easy and fast. A chisel and a good pump, a safe rope, and good tongs, are all the implements requisite for sinking a hole of 2000 ft. deep.

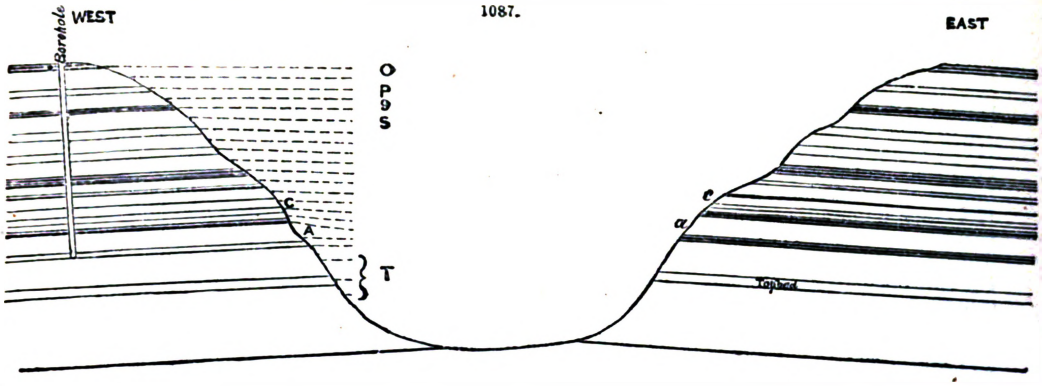
We give an example of boring for minerals, from the 'Transactions of the North of England Institute of Mining Engineers,' vol. vii. The paper which furnishes this example was read by the justly-celebrated Nicholas Wood; we give it and the discussion thereon, without any material alterations, to show the baseless fabric upon which the so-called science of geology is made to rest.

*Nicholas Wood, President of the Institute of Mining Engineers, on the Deposit of Magnetic Ironstone in Rosedale.*—In John Marley's very elaborate and very able account (says *Wood*) of the Cleveland Ironstone District, communicated to this Institute at its meeting of June, 1857, and published in vol. v. of the 'Transactions,' he states:—"The only special district to which I think necessary now to allude is the Rosedale Abbey district, the ironstone from which has attracted a large amount of attention, on account of its large percentage, immense deposit, and magnetic properties."

Marley then gives a history of the discovery of this bed of ironstone, its position in the series, as well as in the district generally, and adds all the information which had then been elicited with regard to the particular features and character of such deposit, which he illustrates by a diagram, showing the explorations which had been made by drifts and pits towards such elucidation; and he then concludes by saying:—"I have no doubt that this seam is the same as the seam at the point *A*, Fig. 1087, as also the same as that found on the east side of Rosedale, in Captain Vardon's property, of varied thickness, as well as the same seam as that at Grosmont, Fryupdale, Swainby, and Boltby, known as *the top seam* of Cleveland—the nine inches of coal in the pit sunk agreeing with *Beckhole*, near Grosmont, in particular; so that the only doubtful point is as to the portion from the outcrop at *A* to the so-called magnetic quarry; the most feasible solution being that it is a disjointed patch of the regular seam, known as the *top seam*, and not a vein, as has been said; and, with all deference to the parties who have had more opportunity for examining this district than I have, I propose leaving the *extent* of the *magnetic and extra percentage* tract as an *unsolved problem*, as it may vary from one or two acres to any indefinite extent, not being at all proved to the south."

This is a very clear and correct account (says *Wood*) of the information then existing on this

deposit, Marley's opinion being that it represented the top seam, as developed at Grosmont Fryupdale, Swainby, and Boltby.




*Reference*:—O, Shale and ironstone ramble. P, Brown and grey sandstone. 9, Coal and shale. S, Shale and sandstone. T, Sandstone; top bed, of iron and lias respectively, not proved by the bore-hole.

*A Section of the Strata at Grosmont is given by Marley as follows*:—

| | Ft. | In. | | | Ft. | In. |
|---|---|---|---|---|---|---|
| Sandstone | 25 | 0 | | Ironstone band and shale | 29 | 0 |
| Ironstone, top seam | 12 | 0 | | "Pecten" band, part of the Cleveland thick seam | 5 | 10 |
| Lias shale | 92 | 0 | | | | |
| Various strata, not identified | 51 | 0 | 198 0 | Shale | 17 | 4 |
| Lias shale | 55 | 0 | | "Avicula" band, Cleveland seam | 6 | 4 |

Another section near Grosmont gives the top seam 11 ft. 6 in., then 187 ft. of shale and ironstone, and then the Cleveland band.

*The Section at Fryupdale is as follows*:—

| | Ft. | In. | | Ft. | In. |
|---|---|---|---|---|---|
| Freestone | 55 | 0 | "Pecten" band, Cleveland main seam | 6 | 0 |
| Top seam | 12 | 0 | Shale | 30 | 0 |
| Jet, cement, and alum rocks | 202 | 0 | "Avicula" band, Cleveland main seam | 4 | 4 |
| Shale | 60 | 0 | | | |

*The Section at Swainby is as follows*:—

| | Ft. | In. | | Ft. | In. |
|---|---|---|---|---|---|
| Shale | 13 | 0 | Shale | 132 | 6 |
| Top seam | 23 | 0 | Cleveland main bed | 9 | 3 |

*And at Felix Kirk, near Boltby, the Section is*:—

| | Ft. | In. | | |
|---|---|---|---|---|
| Brown, yellow, &c., gritstone | 0 | 0 | | |
| Boltby and Rosedale iron rock | 7 | 0 | | |
| Alum shale, or upper lias shale | 116 | 0 | | |
| Upper band of nodular ironstone | 0 | 7 | | |
| Thin seam of soft shale | 3 | 0 | 4 1 | Type of Eston or Cleveland main seam. |
| Lower band of nodular ironstone | 0 | 6 | | |

*Section of Strata in the Hills at Swainby Mines.*

| | Ft. | In. | | |
|---|---|---|---|---|
| Soil, &c. | 3 | 0 | | |
| Freestone | 24 | 0 | | Near the limekiln this is 100, with 9-in. ironstone balls in it. |
| Slaty coal | 0 | 9 | | |
| Shale | 1 | 0 | | |
| Sandstone | 4 | 0 | | |
| Slaty coal | 0 | 9 | | |
| | 6 | 6 | | |
| Shale | 5 | 0 | | |
| Coarse freestone | 3 | 6 | | |
| Shale, with occasional nodules of ironstone | 13 | 0 | | |
| Ironstone, good | 2 | 0 | | |
| Ironstone | 21 | 0 | | |
| | 23 | 0 | | |
| Carried forward | 78 | 0 | | |

*Section of Strata in the Hills at Swainby Mines*—continued.

| | | | | | |
|---|---|---|---|---|---|
| | | | Ft. | In. | |
| | Brought forward .. .. .. | | 78 | 0 | |
| | Shale .. .. .. .. .. .. .. .. | | 132 | 6 | |
| Not Wrought | Ironstone .. .. .. .. .. | 2 8 | | | |
| | Shale .. .. .. .. .. .. | 1 0 | | | |
| | | 3 8 | | | |
| | Ironstone .. .. .. 2 5 | | | | |
| | Shale .. .. .. .. 1 8 | 5 7 | | | |
| | Ironstone .. .. .. 1 6 | | | | |
| | | | 9 | 3 | Scarthnick bed or seam. |
| | Shale .. .. .. .. .. .. .. .. | | 9 | 3 | |
| | Ironstone .. .. .. .. .. | 1 3 | | | |
| | Shale .. .. .. .. .. .. | 0 6 | | | |
| | Ironstone .. .. .. .. .. | 1 3 | | | |
| | | | 3 | 0 | |
| | Shale .. .. .. .. .. .. .. .. | | 16 | 6 | |
| | Ironstone .. .. .. .. .. .. .. | | 1 | 6 | |
| | Supposed shale, but unproved down to the level of the bottom of Crook beck | | 335 | 0 | |
| | | | 585 | 0 | |

*Section of the Strata at Eston Nab, showing the top seam, and the main or Cleveland bed, where the latter is in perfection.*

| | | | | | |
|---|---|---|---|---|---|
| | | | Ft. | In. | |
| Approximated. | Soil, and other strata unproved .. .. .. .. | | 50 | 0 | |
| | Freestone .. .. .. .. .. .. .. .. .. .. | | 60 | 0 | |
| | Shivery post, patches of jet and clay .. .. .. | | 54 | 0 | |
| | | Ft. In. | | | |
| Seam called the "Top Seam." | Nodular ironstone .. .. .. .. .. | 0 1 | | | |
| | Shale .. .. .. .. .. .. .. .. | 2 3½ | | | |
| | Nodular ironstone .. .. .. .. .. | 0 3 | | | |
| | Shale .. .. .. .. .. .. .. .. | 0 7 | | | |
| | Nodular ironstone .. .. .. .. .. | 0 0½ | | | |
| | Shale .. .. .. .. .. .. .. .. | 0 10 | 6 | 0 | Measured working section. |
| | Nodular ironstone .. .. .. .. .. | 0 1 | | | |
| | Shale .. .. .. .. .. .. .. .. | 0 6 | | | |
| | Nodular ironstone .. .. .. .. .. | 0 1 | | | |
| | Shale .. .. .. .. .. .. .. .. | 0 6 | | | |
| | Ironstone band (varies) .. .. .. .. | 0 9 | | | |
| | Aggregate of ironstone, 15½ inches. | | | | |
| Approximated. | Lias shale, including jet rock at bottom .. .. | | 210 | 0 | |
| | Ironstone band .. .. .. .. .. | 0 2 | | | |
| | Shale .. .. .. .. .. .. .. .. | 2 5 | | | |
| | Ironstone band .. .. .. .. .. | 0 2 | | | |
| | Shale, mixed with nodules of ironstone | 1 10 | 10 | 0 | Measured section. |
| | Ironstone band .. .. .. .. .. | 0 3 | | | |
| | Shale .. .. .. .. .. .. .. .. | 1 0 | | | |
| | Shale, inclining in some parts to a fire-clay nature .. .. .. .. .. .. | 4 2 | | | |
| | Aggregate of ironstone, 9 inches. | | | | |
| Cleveland Main or Thick Bed or seam of Ironstone. | Top block, left as roof .. .. .. .. | 0 11 | | | |
| | Parting regular at outcrop, but not so after. | | | | |
| | Second block (left as roof near outcrop) | 2 3 | | | |
| | | 3 2 | | | |
| | Main parting (a good one near the outcrop, but lost farther in). | | | | |
| | Main block and uniform .. .. .. | 12 0 | 17 | 0 | Measured section. |
| | Parting (lost after leaving outcrop). | | | | |
| | Bottom block (varies) .. .. .. .. | 1 10 | | | |
| | | 7 0 | | | |
| | Shale .. .. .. .. .. .. .. .. | 1 8 | | | |
| | Ironstone band (called 2-ft. band) .. | 6 0 | 15 | 6 | |
| | Shale .. .. .. .. .. .. .. .. | 0 10 | | | |
| | Ironstone band .. .. .. .. .. | | | | |
| | Blue shale .. .. .. .. .. .. .. .. | | 36 | 0 | |
| | Various beds of grey post and metal stone, &c. .. | | 93 | 6 | |
| | Total .. .. .. .. .. .. | | 552 | 0 | |

The main features of the sections given by Marley as assimilating to the Rosedale bed, are,

1st. The top seam, varying from 12 to 23 ft. in thickness.
2nd. Lias shale and other strata, 132 ft. to 220 ft.
3rd. The Cleveland main band, 9 to 12 ft.

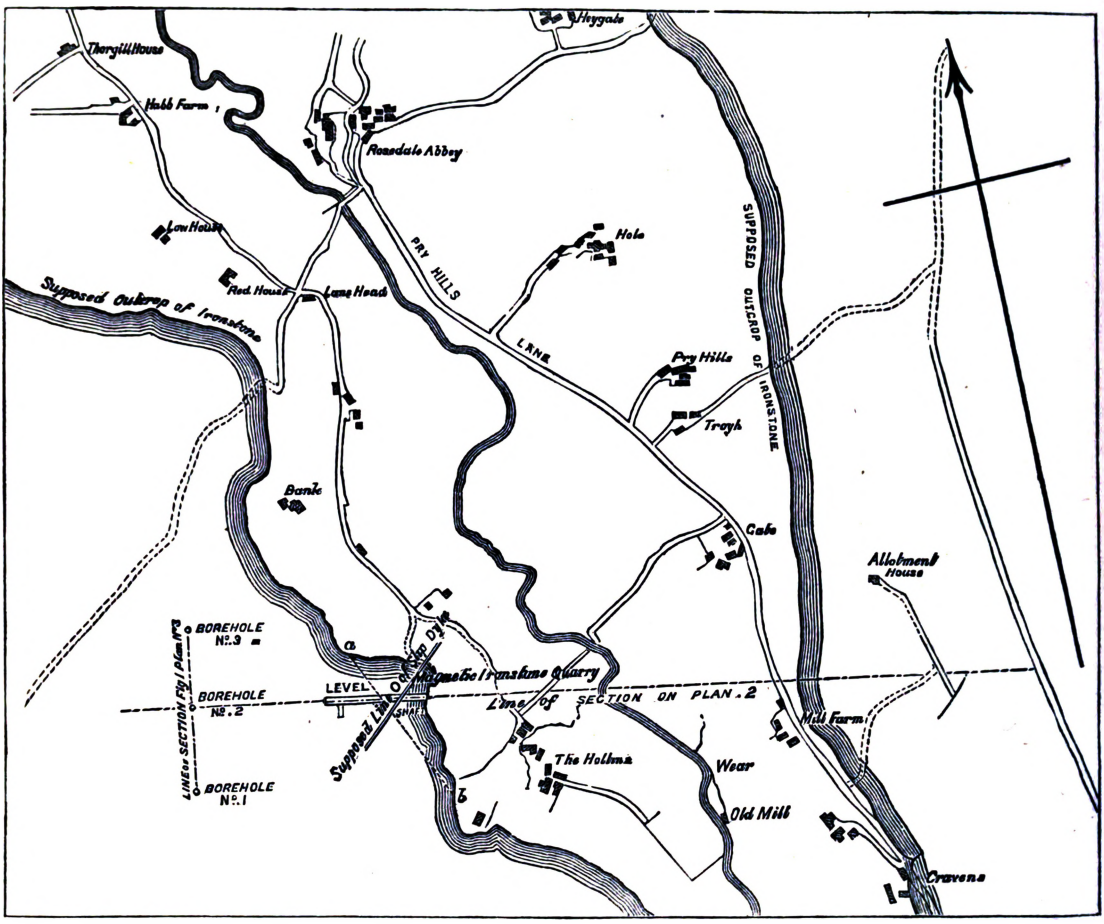
But in all these sections there are no beds of ironstone between the top seam and the Cleveland main band.

Bewick, in a paper presented (says *Wood*) to the Institute, and printed in vol. vi. of the 'Transactions,' gives drawings, and an account of the deposit of Rosedale, and concludes with these remarks,—"My object in thus troubling the members of this Institution with the foregoing remarks is twofold. First, to show that the iron ore of Rosedale, instead of being a large mineral field, as was first asserted, and still believed to be so by many, is nothing more than a volcanic dyke; and secondly, that the ironstone lately opened out in this locality is not, as it is reputed to be, the main seam now being worked in the Cleveland and Grosmont districts, but it is my opinion, if Marley will permit me to say so, the top seam."

I shall now (observes *Wood*) give an account of the operations concluded by Professor Phillips and myself towards the investigation and development of this bed of ironstone.

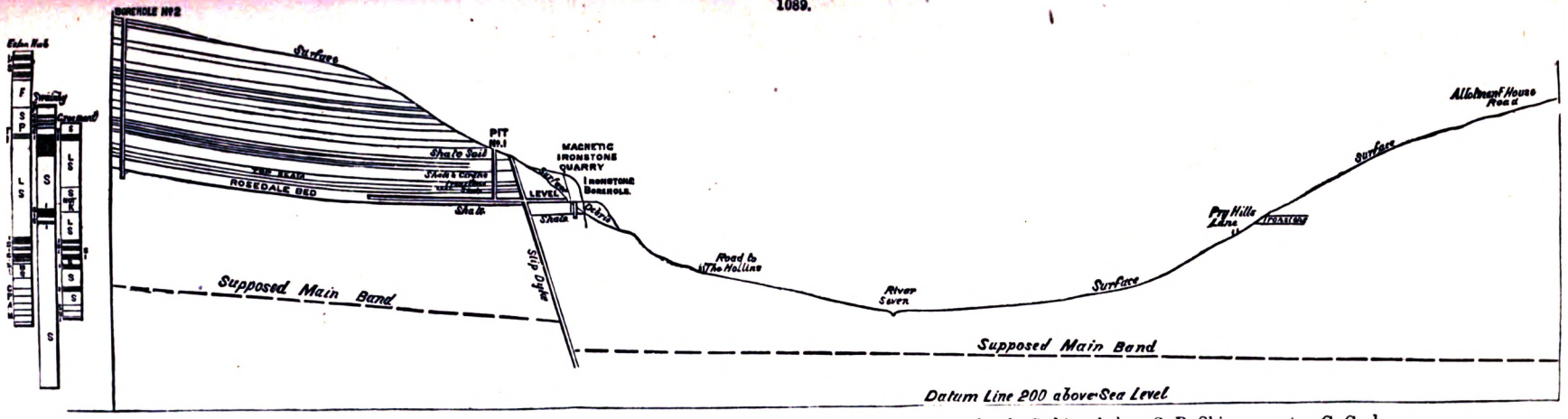
The first discovery of this deposit of ironstone was at a quarry on the south-west side of the valley of Rosedale, about a mile south from Rosedale Abbey, and shown, Fig. 1088. When this

1088.



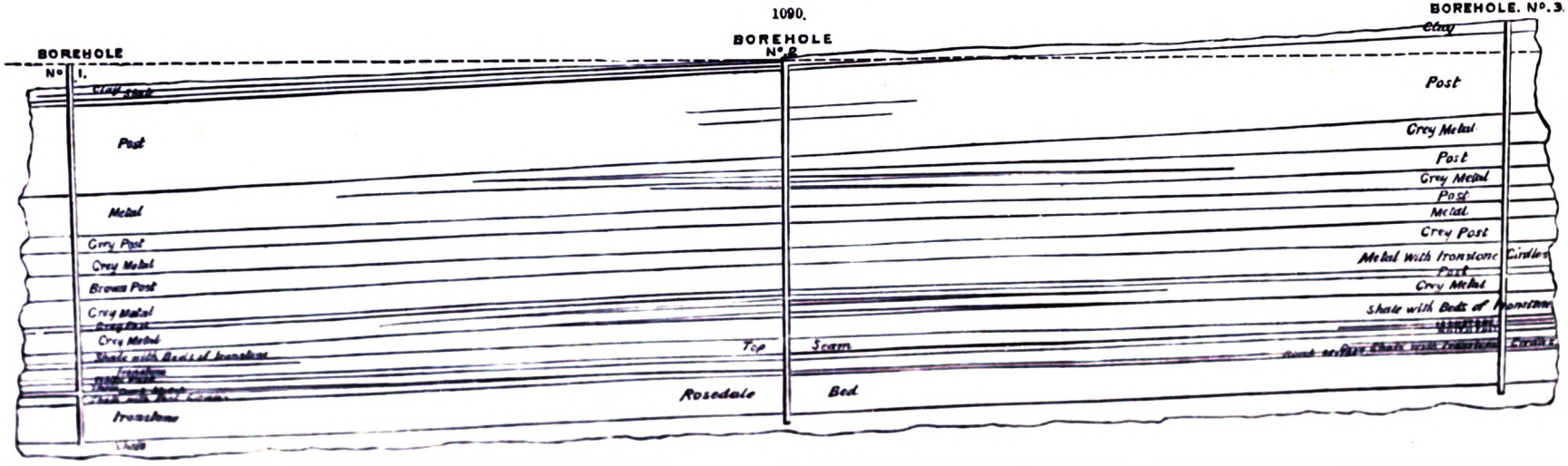

quarry was opened out it was found to consist of apparently a confused mass of ironstone boulders of an ellipsoidal structure, and of gigantic size, often 3 or 4 ft. in diameter; the central part of these boulders being generally blue, and consisting of a solid dark oolitic magnetic iron ore, with, in many cases, sandy and solid ironstone crusts around it; and, in receding from the centre, the iron ore becomes paler, alternating with dark brown purplish layers; the layer then becomes pale brown, and the magnetic quality is lost. In most cases, however, the nodules are quite solid, and a slight stratification exists, though very obscure; and in several cases, likewise, the oolitic structure is merged into compact brown iron ore. In some parts also, where exposed to the water and to the weather, the iron ore is partly washed away, and a gritty ferruginous crust remains. These great variations do not occur where the ironstone is under cover, or covered by other strata, but appears to assume those different phases in consequence of its extreme susceptibility to change by exposure to air and water; and it is somewhat remarkable that the magnetic property is

1089.




*Reference to side sections*:—F, Freestone. S, Shale. I, Ironstone. G, P, M, Grey post and metal. L, S, Lias shale. S, P, Shivery post. C, Coal.

1090.



strongest where the mass is thickest, and scarcely shows any magnetism in places where it is thin, or where it has little cover, and, consequently, more exposed to decomposition or change.

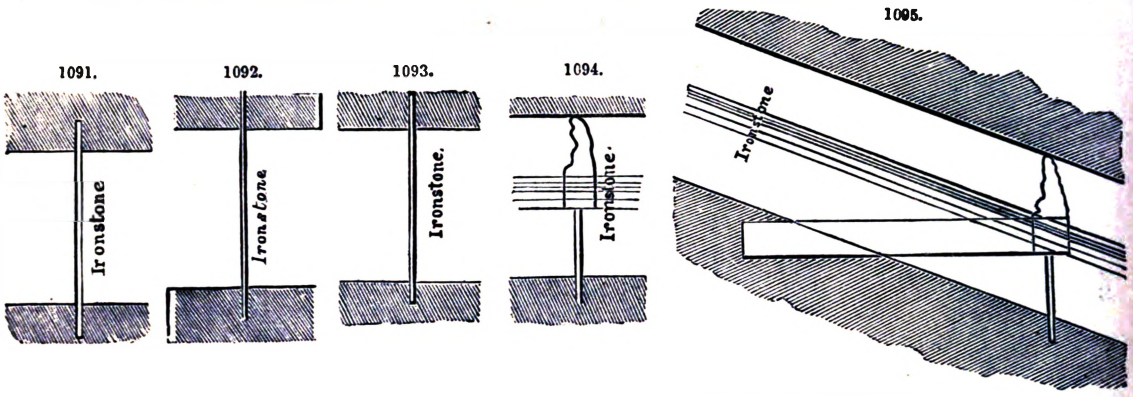
The great characteristic difference of composition between this ironstone and the top and main band of Cleveland is, the entire absence of shells, the structure being entirely of an oolitic character, being entirely composed of small round concretions of iron ore, cemented together with extremely thin siliceous or arenaceous films, and in its magnetic properties exhibiting polarity, and likewise in its greater richness than the ordinary ironstone of Cleveland.

This quarry has been excavated so as to form a face of 60 ft. in thickness; to which must be added 11 ft. of blue magnetic stone, 2½ ft. red ironstone, slightly magnetic, bored down below the bottom in magnetic stone, and 3 ft. of shale.

Soon after the quarry was discovered, it was thought advisable to drive a drift into the side of the hill, to ascertain the extent of this deposit, the quarry being about 600 ft. from the bottom of the valley, and about 300 ft. below the utmost level range, or plateau of moors, lying on the south-west side of the valley. This drift, together with a pit sunk upon it, is shown by a drawing in Marley's paper. Since then, it has been driven to a much greater distance, and three *bore-holes* have been put down from the surface to the Rosedale bed of ironstone.

Fig. 1088 shows the position of this drift, the distance and direction in which it has been driven into the hill, and also the position of the three bore-holes and the quarry. And Fig. 1089 also shows the section of the same drifts, and the section of the borings, together with their depths from the surface, and the beds of ironstone which they have proved. I have carried such section across the valley, for the purpose of showing the position of the ironstone band on the opposite side of the valley.

Fig. 1090 shows, on a larger scale, the strata bored through in the three bore-holes above alluded to, and the ironstone beds which they have proved; Figs. 1091 to 1093, bore-holes, Fig. 1094, facing drift, and Fig. 1095, side drift—show the thickness of the lower bed of ironstone in the several bore-holes in the face of the drift, and also in the side of the drift.




It is necessary to remark that, where the drift was first set away in the side of the hill, it met with shale, and it continued in shale for a distance of about 80 yds., when the ironstone was found. The drift continued in the ironstone for a distance of 180 yds. farther, making a total distance of 260 yds. from the face of the hill. Fig. 1089 is a section of the ironstone at the face or farthest extremity of the drift, showing an entire thickness of 32 ft. of ironstone, namely, 6 ft. 2 in. of drift, 11 ft. 9 in. above the drift, and 14 ft. below it. And, what is important to mention, the ironstone was here distinctly stratified, as shown by the lines across the section, Fig. 1094.

400 yds. in advance of the extreme end of the drift, and 660 yds. from the side of the hill, a *bore-hole*, No. 2, Fig. 1089, was put down; and at right angles to the line of this bore-hole from the drift two other bore-holes were put down from the surface, as shown, Figs. 1089, 1090, each 200 yds. distant from No. 2 bore-hole, or 400 yds. separate; and the following are sections of the strata passed through in these bore-holes.

*Account of the Boring No.* 1, *Fig.* 1090, *or South Bore-hole, on Rosedale Moor.*—1858.

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| 1 | Clay | 0 | 5 | 0 |
| 2 | Metal or shale | 1 | 1 | 0 |
| 3 | Brown freestone water | 12 | 5 | 6 |
| 4 | Metal or shale | 6 | 1 | 6 |
| 5 | Brown and grey post | 2 | 0 | 0 |
| 6 | Grey metal | 3 | 2 | 0 |
| 7 | Brown and grey post | 3 | 4 | 8 |
| 8 | Grey metal | 3 | 4 | 9 |
| 9 | Grey post | 0 | 5 | 6 |
| 10 | Grey metal | 3 | 1 | 10 |
| | | 38 | 1 | 9 |
| 11 | Ironstone, magnetic | 0 | 4 | 0 |
| 12 | White shale mixed with ironstone | 0 | 5 | 0 |
| | Carried forward | 39 | 4 | 9 |

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| | Brought forward | 39 | 4 | 9 |
| 13 | Ironstone, magnetic | 0 | 5 | 0 |
| 14 | Shale mixed with ironstone | 1 | 0 | 9 |
| 15 | White post | 0 | 2 | 4 |
| 16 | Shale | 1 | 1 | 0 |
| 17 | Dark metal | 0 | 3 | 0 |
| 18 | Shale with post girdle | 1 | 5 | 3 |
| | | 45 | 4 | 1 |
| 19 | Ironstone, magnetic | 5 | 2 | 0 |
| 20 | Inte. shale | 0 | 1 | 6 |
| | Total depth, fathoms | 51 | 1 | 7 |

*Account of the Boring, the Middle Hole, or No. 2, Fig. 1090, on Rosedale Moor.*—1857.

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| 1 | Freestone ramble .. .. | 0 | 3 | 0 |
| 2 | Metal .. .. .. .. .. | 0 | 4 | 0 |
| 3 | Brown post .. .. 5 2 0 | | | |
| 4 | Grey post .. .. 1 3 0 | 12 | 1 | 0 |
| 5 | Brown post .. .. 5 2 0 | | | |
| 6 | Metal .. .. .. .. .. | 5 | 3 | 0 |
| 7 | Post with water .. .. .. | 0 | 5 | 0 |
| 8 | Metal .. .. .. .. .. | 0 | 5 | 0 |
| 9 | Coal .. .. .. .. .. | 0 | 0 | 4 |
| 10 | Metal .. .. .. .. .. | 0 | 2 | 6 |
| 11 | White post with water .. | 0 | 3 | 0 |
| 12 | Metal .. .. .. .. .. | 2 | 1 | 6 |
| 13 | Grey and brown post .. .. | 2 | 3 | 0 |
| 14 | Metal .. .. .. .. .. | 3 | 2 | 0 |
| 15 | Brown post .. .. .. .. | 2 | 3 | 6 |
| 16 | Metal .. .. .. .. .. | 3 | 5 | 0 |
| 17 | White post .. .. .. .. | 0 | 4 | 0 |
| 18 | Metal .. .. .. .. .. | 0 | 5 | 5 |
| | Carried forward .. | 37 | 3 | 3 |

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| | Brought forward .. | 37 | 3 | 3 |
| 19 | White post .. .. .. .. | 0 | 1 | 3 |
| 20 | Metal .. .. .. .. .. | 1 | 3 | 6 |
| 21 | White post .. .. .. .. | 0 | 3 | 3 |
| 22 | Metal ironstone girdles .. | 2 | 5 | 0 |
| | | 42 | 4 | 3 |
| 23 | Ironstone .. .. .. .. | 2 | 1 | 3 |
| 24 | White post mixed with whin | 1 | 2 | 0 |
| 25 | Metal with ironstone girdles | 1 | 1 | 6 |
| 26 | Black metal mixed with ironstone .. .. .. .. .. | 0 | 4 | 0 |
| | | 48 | 1 | 0 |
| 27 | Ironstone .. .. .. .. | 5 | 2 | 0 |
| 28 | Inte. grey shale .. .. .. | 1 | 1 | 0 |
| | Total depth, fathoms .. | 54 | 4 | 0 |

*Account of the Boring, No. 3 Hole, Fig. 1090, or North Hole, on Rosedale Moor.*—1858.

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| 1 | Clay .. .. .. .. .. | 1 | 1 | 0 |
| 2 | Brown post .. .. .. .. | 11 | 5 | 0 |
| 3 | Grey metal .. .. .. .. | 4 | 1 | 0 |
| 4 | Brown post .. .. .. .. | 3 | 3 | 6 |
| 5 | Grey metal .. .. .. .. | 2 | 0 | 0 |
| 6 | Brown post .. .. .. .. | 2 | 1 | 0 |
| 7 | Grey metal .. .. .. .. | 2 | 5 | 0 |
| 8 | Brown or grey post .. .. | 3 | 0 | 0 |
| 9 | Grey metal ironstone girdles | 4 | 1 | 0 |
| 10 | Grey post .. .. .. .. | 0 | 4 | 6 |
| 11 | Grey metal .. .. .. .. | 2 | 5 | 6 |
| | | 38 | 3 | 6 |
| 12 | Ironstone, magnetic .. .. | 0 | 4 | 6 |
| 13 | White shale, mixed with ironstone .. .. .. .. | 1 | 1 | 0 |
| | Carried forward .. | 40 | 3 | 0 |

| No. | | Fms. | Ft. | In. |
|---|---|---|---|---|
| | Brought forward .. | 40 | 3 | 0 |
| 14 | Ironstone .. .. .. .. | 0 | 3 | 0 |
| 15 | Shale, mixed with ironstone | 0 | 5 | 9 |
| 16 | Gullity post .. .. .. | 0 | 0 | 9 |
| 17 | Ironstone, magnetic .. .. | 0 | 5 | 6 |
| 18 | Light-coloured ironstone .. | 0 | 3 | 0 |
| 19 | White post, mixed with whin | 1 | 1 | 0 |
| 20 | Ironstone, magnetic .. .. | 0 | 3 | 0 |
| 21 | Grey shale, mixed with ironstone and post girdles .. | 1 | 2 | 6 |
| 22 | Black metal .. .. .. .. | 0 | 2 | 6 |
| | | 47 | 0 | 0 |
| 23 | Ironstone, magnetic .. .. | 4 | 5 | 3 |
| 24 | Inte. shale .. .. .. .. | 0 | 4 | 0 |
| | Total depth, fathoms .. | 52 | 3 | 3 |

It will be seen, therefore, that for a distance of 580 yards from the pit, No. 1 on the section, Fig. 1089, to the boring No. 2 on the same section, the thickness of this bed of ironstone is nearly the same, and that this is the case likewise at the other two bore-holes, Nos. 1 and 3, at right angles to the above line of section, the respective thicknesses being as follows:—

| | Ft. | In. | | Ft. | In. |
|---|---|---|---|---|---|
| Drift .. .. .. .. | 32 | 0 | No. 2 bore-hole .. .. | 32 | 0 |
| No. 1 bore-hole .. .. | 32 | 0 | „ 3 „ .. .. | 29 | 3 |

These borings and sections show two distinct beds of ironstone, stratified with great regularity; and they prove most conclusively that neither of them is at all like what Bewick terms "nothing more than a volcanic dyke."

It will be seen by the map of the district, Fig. 1088, that a border is traced around the edge of the valley; this is undoubtedly the outcrop of what is called the "top seam" of ironstone, as it can be traced south and east into Eskdale, and towards Grosmont and Fryupdale; and also north towards Swainby and Boltby, in which localities Marley has given sections of the top seam, and also of the Cleveland main band. Supposing this outcrop in the Rosedale valley to be the top seam, then the upper bed in the sections, Figs. 1089, 1090, is unquestionably the top seam likewise; and we there have a bed of ironstone upwards of 30 ft. thick, lying parallel to and strictly conformable with the "top seam" (and separated therefrom only by a thin bed of shale), of an entirely different character from either such top seam or the main band of Cleveland.

I have (says *Wood*) laid down on plan, Fig. 1089, a section of the strata given by Marley, at Grosmont to the south-east, and at the Swainby mines to the north; and I have added the section at Eston Nab. It should be observed, also, in corroboration of the upper bed of ironstone, Fig. 1089, being the top seam, that a bed, or rather three or four beds, of ironstone intermixed with shale occur in the brook of Rosedale and crops out in the bank, which is generally believed to be the representative of the Cleveland main band, though the ironstone is very inferior, and not workable. I have laid down on the section, Fig. 1089, the position of this bed of ironstone, which agrees pretty well with its position in the other sections, making allowance for the variation in the thickness of the lias shale as found in the several localities.

I have (observed *Wood*) likewise, in Figs. 1088, 1089, shown the position of the quarry, which

appears to have slipped down below the level of the beds, as shown by the drift and borings. This appears to have been occasioned by a slip-dyke which crosses the drift near the pit, as shown on the plan, Fig. 1088. It will be seen by this plan that the drift passed through alluvial soil and shale up to near the pit, when this dyke was crossed and the ironstone cut, as shown on the plan. This dyke is supposed to run in the direction shown on the plan, crossing the drift near the pit, and throwing the strata down on the south-west side, and, consequently, the strata comprising the quarry; and it appears that the quarry itself is much broken, and has very much the appearance of a disjointed slip, the elliptical nodules being in a mass of confusion, as shown on the plan.

It has been supposed by some parties that this dyke has given the magnetic character to the ironstone; but it is well known that the character of the ore must be changed from a peroxide to a protoxide to become magnetic, which the crossing of the dyke through the strata could scarcely accomplish; and then we have the entire absence of shells in the lower bed, while the matrix of the upper bed or top seam is entirely calcareous and filled with shells. The concretionary nature of the stone, and the much greater percentage of iron produced by this deposit over that of either the top seam or the Cleveland main band, are also characteristic of this bed of ironstone; the analysis given by Marley of the Rosedale stone being upwards of 50 per cent. of metallic iron, while the top seam and main band are about 32 to 35 per cent.; and the produce of a large quantity smelted at Consett gave 55 per cent. from the calcined ore, and 45 per cent. from the raw stone.

Whatever opinion may, therefore, be formed of the cause of this deposit, we certainly have the fact that, for a width of 400 yds. and a length of 580 yds., we have a bed of ironstone highly magnetic, of an almost entirely uniform thickness, totally different in its mineralogical character from the ordinary stone of the district, and yielding in produce nearly 20 per cent. more iron in the furnace. To what extent this bed may exist beyond the extent already proved will be the subject of further investigation; but it will be a very extraordinary anomaly in geology if a bed of such uniform thickness should not extend to considerable distances. It has been stated that a similar bed has been discovered in other and distant localities; not being myself cognizant of the facts, and my information not being very precise, I abstain (says *Wood*) from giving such information at present. The importance of such discoveries are of too great interest in the district, and too valuable in a commercial point of view, to remain long unexplored, and therefore we may hope that at some future period the Institute will be favoured with an account of such deposits.

The President's paper on the Rosedale Ironstone having been read, a discussion thereon was taken.

*Bewick* said the magnetic ore in the quarry was a casual deposit in the shape of a dyke or vein.

*Marley.*—I understand, since I was at Rosedale Abbey, that which the President stated to be the top seam had been discovered in a regular stratified state on the south side of the magnetic quarry. At the last discussion we had on the subject, I admitted if that bed of ironstone had been discovered keeping on its uniform rise and dip, from the north side of the quarry to the south, I had been mistaken in supposing the magnetic seam to be the same as that of the seam then discovered on the north side of the quarry. Then, as to whether it was a vein or a bed, or whether, what I supposed at the last meeting, it was an overflowing between soft strata, similar to "flats" in lead veins, I had not an opportunity of forming an opinion, for want of the *three bore-holes*, which have now been given.

The *President.*—What you stated was quite correct. The top seam had not then been found on the south side of the quarry. It is now found on the south side as well as the north side; but I do not think we have yet discovered the magnetic stone on the south side of the quarry, except in the drifting and borings.

*Marley.*—When I made my examination, preparatory to reading my paper, the top seam at the point *A* on Fig. 1087, therein referred to, was lost, and no continuation was found south of the magnetic quarry; but, by competent witnesses, I have been informed it is now found south of the said magnetic quarry. But, if the magnetic stone is a bed, it is extraordinary so large an extent of country should give no trace of it, as at Grosmont and other places we have not the slightest trace of it. At Ingleby they are putting three bore-holes down, with a view of proving the existence or otherwise of the magnetic ironstone there. They are now, I believe, past the top-seam position, but have got nothing but shale yet. These borings will prove about 100 fathoms of strata. I have hitherto been of opinion that the round particles, in the specimens of magnetic ore, are oolitic shells.

The *President*, *N. Wood.*—No. I believe they are iron, with a siliceous matrix.

*Marley.*—Has one of those globules ever been analyzed by itself, and found to be pure iron?

*Wood.*—I do not know; but I believe there is no calcareous matter in those particles which there would be if it were shells.

*Marley.*—Unless it is some peculiar formation.

*Wood.*—Then the shell is gone, and the iron left.

*Boyd.*—The chemical part of the shell remains in the Cleveland stone.

*Marley.*—The magnetic stone is not in analogy with the Cleveland.

*Wood.*—It has changed its character from a peroxide to a protoxide.

*Marley.*—I acknowledge the magnetic stone is free from "pectens."

*Bewick.*—After hearing what has been stated by our President, I am bound to say our opinions are as much opposed as ever; and I shall endeavour to show you that the ironstone beds they have BORED THROUGH at Rosedale Abbey are not the same as the magnetic ore and top bed found by the side of the valley, that, in fact, the borings have not reached those deposits by several feet, and that, therefore, *they have not as yet proved anything more respecting them.* The strata they have bored through are quite above them, and you will find on looking at the table of the borings,

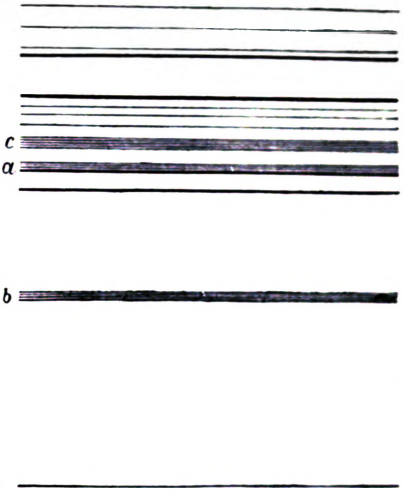
published with the July discussion, that an important member of the series, which immediately overlies the top bed, is wanting. I allude to the great sandstone rock, which is seldom under 50, and sometimes met with 100 ft. thick. This rock does not appear in the borings at all.

*Wood.*—Yes, it does, namely:—

| | | Fms. | Ft. | In. | |
|---|---|---|---|---|---|
| Brown freestone .. | No. 1 bore-hole .. .. | 12 | 5 | 6 | with other beds of post, mixed with shale. |
| Brown and grey post | „ 2 „ .. .. | 12 | 1 | 0 | |
| Brown post .. .. | „ 3 „ .. .. | 11 | 5 | 0 | |

*Bewick.*—That is not the sandstone I allude to. That rock is found higher in the series, and belongs to the coal measures, which your *bore-holes* have gone through; but, as I have just said, they have not yet reached the other sandstone, and cannot, therefore, have touched the top bed. In this section, Fig. 1096, you have, in my opinion, a type of the ironstone you have gone through in your borings. The seams here are thin and divided, and the shale between them is interspersed with iron nodules; and, as you admit the seams are split in the last *bore-hole*, it but serves to confirm my opinion that they are one and the same. They occupy the same geological position in the series—that is, they intervene the great sandstone rock and the coal measures in the oolitic series.

1096.

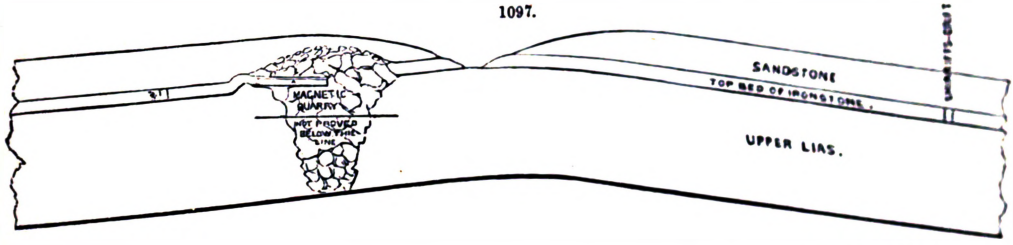



*Reference:*—1, 2, 3, Sandstone, shale, and coal. 4, Sandstone. 5, Upper lias. *a*, *b*, *c*, Ironstone.

*Wood.*—Do you purpose giving the sections for publication?

*Bewick.*—Yes; I intend leaving the whole of the sections with you for that purpose. The thickness of every stratum, in the diagram representing a cross-section of the vale of Rosedale, is taken from the table of the borings before referred to, in which I may here observe there is an error of 3 fathoms 2 ft. The total ought to be 48 fathoms 2 ft. instead of 51 fathoms 4 ft.; and if you take from this 1 fathom 1 ft. for the grey shale they have left off in, below the ironstone, it leaves 47 fathoms 1 ft. from the top of the bore-hole to the bottom of the ironstone. I am thus particular because I have taken a line of levels, commencing at the south drift, by the side of the hill, and terminating at the *south bore-hole;* and I find there is a difference in the height of the level, and the depth of No. 2 *bore-hole*, Fig. 1090, of 64 ft., fully corroborating what I have before stated, namely, —That the *bore-holes* have not yet reached the sandstone which overlies the top bed; and if you will allow me to explain my sections, I think they will prove to you that the ironstone they have cut through belongs to that which we call the oolitic beds, and which are found in different localities in the Grosmont district, not so thick, it is true, neither are they magnetic; but they are found, as I before stated, occupying the same geological position, and accompanied by the same description of strata. Section, Fig. 1096, is taken between Goathland Mill and Beckhole, near Grosmont, which, you will observe, contains the same alternating strata of sandstone, shale, coal, and ironstone, as you see in section, Fig. 1087, which is a transverse section of the vale of Rosedale, representing the strata they have bored through there. The ironstone beds *a* and *c*, in section, Fig. 1096, are, in my opinion, the same as those marked *a* and *c* in section, Fig. 1087. The bed *c* is very irregularly diffused throughout this portion of the oolitic district. It is found in the nodular form. In some places you find it of considerable thickness, and then, again, entirely wanting. Sometimes of good quality, but more frequently coarse and inferior, and gradually alternating with the sandstones. The bed *a* is more regular, but thinner, and of very good quality; its upper portion consists of a nodular bed averaging from 3 to 6 in.; and the lower portion a bed averaging from 12 to 18 in. in thickness. Wherever I have met with those beds, however, I have always found them so variable, both in extent and thickness,

1097.




as to afford no reasonable prospect of their paying for working. They may certainly be found different at Rosedale; but I would just observe that I consider *boring a most fallacious mode of proving ironstone deposits in strata* such as that which these borings have gone through, you are so liable to mistake a nodule for a bed, or a portion of a bed. I shall be much surprised if you do

not find the section of your shaft, should you sink one, very different from the section of your *bore-hole*.

*Wood.*—Then it is a question of policy, in Bewick's view of the case, commercially considered, whether the borings should not be continued. With regard to the identity of the position in the series of the bed of ironstone ranging around the Rosedale valley, as shown in Fig. 1097, and also in Fig. 1087, it appears to be undoubtedly the top bed of Cleveland. All parties admit this. Then the question is, Is the bed of ironstone proved at the pit No. 1, Fig. 1089, and the bed corresponding therewith and proved in the bore-holes Nos. 1, 2, and 3, and therein designated by me as the top seam, the same bed of ironstone? Bewick thinks not, and that the borings have not yet reached this bed. I can, of course, only refer to the borings, driftings, and the section of pit No. 1, and I must add that there appears to me no doubt whatever on the subject; and the fact that, according to Bewick's plan, Fig. 1097, we have the top bed on both sides of the magnetic quarry, ranging as accurately as can be conceived with this bed in the borings, confirms this supposition, in my opinion. It is true that this bed is at a lower level at the south or left-hand drift than on the north side, but this is clearly the effect of the dyke shown in Fig. 1087, which throws down the strata in that direction. With regard to the supposed want of what Bewick calls the thick sandstone strata immediately above the top bed of ironstone, and shown on the section, Fig. 1096, to be 100 ft. thick, I have looked carefully over the sections given in Marley's paper, and I do not find in any one of them, except at Eston Nab, the extreme northern point of the district, any bed of sandstone approaching to that thickness, and there the section given is

| | Ft. | In. |
|---|---|---|
| Freestone .. .. .. .. .. .. .. .. .. .. | 60 | 0 |
| Shivery post, patches of jet, and fire-clay .. .. .. | 54 | 0 |
| Top seam, exclusive of shale bands .. .. .. | 1 | 3 |

At Rosedale Cliffs, between Staiths and Runswick Bay, we have

| | | |
|---|---|---|
| Freestone .. .. .. .. .. .. .. .. .. .. | 26 | 0 |
| Fire-clay .. .. .. .. .. .. .. .. .. .. | 4 | 6 |
| Freestone shale .. .. .. .. .. .. .. .. .. | 5 | 5 |
| Blue shale .. .. .. .. .. .. .. .. .. .. | 0 | 10 |
| Top seam, exclusive of shale bands .. .. .. | 4 | 7 |

Still farther south, the sandstone at Wreck Hill is only 10 ft., with 2 ft. 6 in. of shale covering the top seam; and at Grosmont, Marley gives 25 ft. of sandstone, and another section at 58 ft. 6 in., which he says varies in thickness and quality. At Fryupdale, the thickness of sandstone is given at 55 ft., and at another place, namely, Swainby, the following is the section:—

| | Ft. | In. | |
|---|---|---|---|
| Soil, &c. .. .. .. .. .. .. .. .. .. | 3 | 0 | |
| Freestone .. .. .. .. .. .. .. .. .. | 24 | 0 | Near the limekiln this is 100, with 9-inch ironstone balls in it. |
| | Ft. | In. | |
| Slaty coal .. .. .. .. .. .. .. | 0 | 9 | |
| Shale .. .. .. .. .. .. .. .. | 1 | 0 | |
| Sandstone .. .. .. .. .. .. .. | 4 | 0 | |
| Slaty coal .. .. .. .. .. .. .. | 0 | 9 | |
| | 6 | 6 | |
| Shale .. .. .. .. .. .. .. .. | 5 | 0 | |
| Coarse freestone .. .. .. .. .. .. | 3 | 6 | |
| Shale, with occasional nodules of ironstone | 13 | 0 | |
| Top seam .. .. .. .. .. .. .. | 28 | 0 | |

Considering, therefore, that in the borings there is about 60 ft. of sandstone, there does not appear to me any substantial difference between the shale in those borings and in the other parts of the district to justify the supposition that the upper bed of ironstone is not the top seam. Bewick thinks the bore-holes have not reached the sandstone he describes. If so, he should like to ask Bewick what seam of ironstone that is in the district which has been bored to?

*Bewick.*—It is, in my opinion, as I have previously stated, the ironstone found in the oolitic series.

*Wood.*—Where does it occur in the other districts? Where do you find another similar deposit in Mr. Marley's sections?

*Marley.*—Dr. Verity gives a variety of ironstone seams. If you refer to my paper, you will find there are several ironstone seams lying over the seam, which we agree to be the top seam of Cleveland. Professor Phillips said that, with the exception of the classification of names, this section was practically correct.

*Wood.*—Do you think the ironstone which crops out all around the valley of Rosedale is the top seam?

*Bewick.*—I think so; I have no doubt about it.

*Wood.*—If we are agreed about the deposit of ironstone found cropping out around the valley of Rosedale, as shown in the different plans, then there can be no difficulty in tracing the sandstone overlying that bed to the sandstone first of all sunk through at the pit, Fig. 1089, and thence to the borings Nos. 1, 2, and 3; and these borings having passed through the upper bed of ironstone, below such sandstone, and then through the magnetic bed, there cannot be the least doubt of the geological position of these beds. With reference to the levels, there is no discrepancy whatever

in that respect; there is a rise in beds in the line of the drift, and in the extension of that line to the borings, and the direction of the line between the borings seems to be nearly water-level at that part. There is not, therefore, the least discrepancy on this point. I have taken the Ordnance maps as my guide as regards the levels, and have no doubt they are correct. Whatever opinion may, therefore, be arrived at with respect to the comparison of the beds proved in the borings and in the pit, with the beds at Grosmont, &c., there appears no doubt in my mind that the mass of ironstone of the quarry is a detached portion of the thick or lower bed of ironstone, and that such bed exists *in situ* for a considerable, and, of course, at present, for an unknown extent in the locality of Rosedale.

*Bewick.*—If our President means by pit Fig. 1089 the air-shaft sunk on the main drift, I quite agree with him that the sandstone found in that shaft is the same as that which overlies the top seam; but, I beg to say, I entirely differ from him in supposing it to be the same as that they have gone through in the borings. I am also opposed to his opinion with reference to the direction of the dip and rise of the strata. There can be no doubt, I think, but the strata on the west side of Rosedale, *and to the south of the crown*—that is, the point from whence the strata dip in contrary directions—are dipping in a south-westerly direction, as shown in my section, Fig. 1097, and still more clearly proved by the drift commenced on the south side of the magnetic dyke, and driven in a line with the south bore-hole, running nearly west, but which has been discontinued, owing to the top seam, in which the drift was commenced, dipping so much in that direction, instead of rising, as our President supposes, as, at the distance of not many yards, to be completely under water-level. With reference to the slip-dyke or fault mentioned by that gentleman, I can only state that I have never yet been able to discover any dislocation or disturbance of the strata, other than what has been occasioned by the dyke of magnetic ore in its immediate vicinity. Then, as to the extent of the magnetic ore, all I can say is, I have paid several visits to Rosedale solely for the purpose of examining the strata in that neighbourhood, the many deep ravines which abound there affording ample opportunity for doing so, but I have never been able to trace the magnetic ore beyond the vicinity of the quarry, and every visit only serves to convince me that it is a casual deposit, in the shape of a dyke or vein. A bed, however, of 560 yds. in length, and from 30 to 32 ft. thick, cannot be identified with a casual deposit; nevertheless, I think, very probably there may be a mistake in supposing you have a solid mass of ironstone 32 ft. thick. This may have occurred from the borers having cut through nodules or irregular patches of ironstone, and also from the shale in which it is found being very hard, and of the same colour as the ironstone. From these circumstances it is an easy matter to be misled by borings.

*Wood.*—Whatever may have been the result of investigations on the surface, I do not think I can add any further information to that already given and shown on the plans, to prove that a thick bed of ironstone of about 32 ft. exists over a space of upwards of 560 yds. in length, and 200 yds. in width, with not the least indication of any change or termination of such deposit. It would, indeed, be a most extraordinary occurrence in the annals of boring, to suppose that occasional nodules, or irregular patches of ironstone, should have produced the result recorded in these borings. The boring through the ironstone beds was performed under the immediate inspection of *Stott*, a well-known experienced borer, who kept the specimens brought up the bore-hole; and I can add, that I examined a great many of the specimens myself with a magnet, and found them magnetic. There is not the least pretence for supposing that shale could be mistaken for ironstone. Have you seen any nodular magnetic ironstone in the Grosmont district?

*Bewick.*—Never. You must remember (addressing the President) that you stated at the October discussion in 1857, that Professor Phillips and yourself had discovered the magnetic ore in "two localities two miles apart," namely, at Sheriffs drift and at the Quarry; and, again, in the July discussion of last year, you stated the stone in the drift south of the dyke was magnetic, but on examining it I found this not to be the case as regards both the drifts. I believe the reason why there are so many conflicting opinions with reference to the nature and extent of the magnetic ore is owing to the difficulty there is in distinguishing the ore from the top bed—that is, in separating the igneous portions from the sedimentary; for, although they are both frequently magnetic in the immediate vicinity of the dyke, there is yet a vast difference between them. The igneous portion is harder, heavier, and more compact than the sedimentary; and the former appears to have acted upon the latter whilst in a heated condition, much in the same way as a magnet acts upon a piece of common iron, imparting to it a portion of its peculiar magnetic properties. I may here be permitted to add, that whilst I believe this ore to have been subject to a heat sufficient to evolve the different gases it contained, I yet do not think the heat has been of that intensity so as *entirely* to expel them. We need not, therefore, be surprised at *traces* of carbonic acid being found in the chemical analysis of this ore. Here is a specimen of the igneous portion, which I took from the bottom of the quarry, and, after examining it, no one can doubt, I think, of its having been subjected to heat.

*Wood.*—There is no doubt, as stated by Mr. Bewick, that portions of the top bed in Rosedale are occasionally magnetic, and it was this property which led to the mistake, if there are mistakes, in supposing the magnetic bed to have been discovered at Sheriffs drift, and at the drift south of the magnetic quarry. The explorations at that time had not been sufficiently extended, nor have they yet been prosecuted to such an extent as to ascertain if the magnetic bed exists in those localities. Finding part of the ironstone partaking of magnetic influence led to a supposition that this bed did exist in those localities, and the subsequent explorations have not been prosecuted to an extent to ascertain the fact either one way or the other. To *Bewick.*—From what part of the quarry did you take this specimen?

*Bewick.*—It is from the floor of the quarry. This (showing another specimen) is a sample of the top bed which appears to have been partially burnt, and you will at once be able to detect the difference between them. These (showing other specimens) are samples of the ironstone found in the oolitic rocks, in the neighbourhood of Grosmont, some of the nodules of which are amongst

the richest of the clay or calcareous ironstones. I omitted to state that, with the exception of the first 60 ft., where the ground was so steep that I could not fix my instrument, and from which there may be some slight inaccuracies, I took my levels with a good and safe instrument, and the operation was performed in the ordinary way of back and fore sights. I find the difference between my levels and what I suppose the correct position of the top bed of ironstone, and that shown by the bore-holes, to be 64 ft.

*Wood.*—The question of the difference of the levels rests entirely upon the assumed inclination of the beds; a difference of level of 64 ft. in a distance of 400 yds., accords, in my opinion, with what may be supposed to be the regular inclination of the beds.

*Bewick.*—Yes; but in your section you connect two sandstones which have nothing to do with each other, namely, the sandstone found in the air-shaft immediately overlying the top bed, and the sandstone found in the bore-hole, between which there are several feet of *alternating strata;* and to do which you must of necessity raise your level line, and show the strata to be rising in that direction; but the drift you have driven some distance into the side of the hill, and at the same point as my line of levels, shows the strata to be *dipping in that direction.* I may mention, too, that had another bed of 32 ft. thick really been met with in the bore-hole, it must have been found along the sides of the valley, which are intersected in so many places with mountain streams, all of which have been searched by persons having a fair knowledge of the geology of the immediate neighbourhood, but without the least trace of it having been met with.

*Wood.*—I cannot think that there is the least doubt that the sandstone in the pit, No. 1, Fig. 1089, is the same sandstone as that proved in the borings; all the appearances on the surface, as well as the general rise and dip of the strata, prove this. Extending the line of section across the valley, it is clear there is a general rise of strata along the line of section. No doubt the strata in the drift dip towards the west, but that is no doubt influenced by the slip-dyke which crosses it. I would observe that, taking the line of section along the face of the valley in Fig. 1087, in the direction of the dotted line *a b*, and applying the inclination of the top bed of ironstone, shown Fig. 1097, to that line, and not to the curved or projecting line along the face of the hill, the position of the bed would be rising from *a* towards *b*, and it would require a slip-dyke, shown Fig. 1087, to throw the bed into its proper position along the face of the valley to the west of the magnetic quarry. On examining Fig. 1087 it will be seen that the magnetic quarry and the top bed of ironstone, as shown in Fig. 1097, project considerably to the east of the general line of the side of the valley, which, being towards the dip of the strata, shows the top bed at a lower level than if the section had been continued in a more direct line, or in the direction *a b*. Whatever conclusion, therefore, may be arrived at after all the explanations given, we have the fact of an almost horizontal bed of ironstone, and of nearly a uniform thickness, distinct in character from the ordinary beds of the district, extending over a length of 568 yds. and a width of 200 yds., which clearly proves that it is not a vein. How much greater distance it extends, must be left to future explorations to prove; but it would certainly be an extraordinary anomaly in geology for such a thickness of strata to disappear altogether in a short distance. If it extends across the valley, as shown in *Bewick's* plan, Fig. 1096, then there is no reason to suppose that it may not extend to the same distance to the north; and if, according to Bewick, the borings have not yet reached to the top bed of ironstone, then the deposit of ironstone, in the valley of Rosedale, is richer in ore than either Professor Phillips or myself has set forth. The correct extent must, however, be left to future explorers to discover. Enough has been proved to show a most extraordinary deposit of a very peculiar and rich ironstone, and well worth further investigation.

*Bewick.*—There is a section of the cross drift, shown in Fig. 1089, driven at right angles from the main drift to prove the breadth of the dyke, and which, at the distance of 16 yds., cuts the shale, and apparently touches the top seam at the same time. At the distance of 6 yds. the stone in this drift ceases to be magnetic. It is, therefore, incomprehensible to me how it can again become so at the distance of 200 yds. from this point. Of course, you have a right to infer from the information that reached you that such is the case. Still I would strongly recommend that the borings should be continued to prove whether the sandstone be below you or not, to ascertain which could not fail to give great satisfaction to all concerned; the cost would not be great, as the bottom of your borings must be near the top of that rock.

*Wood.*—The cross drift was not sufficiently extended to the west to prove the dyke, but, as there was a considerable rise of the strata in that direction, no doubt such an inclination has been occasioned by the proximity of the dyke, shown on the plans, Figs. 1087, 1088. All the facts show that the slip-dyke has been a dislocation subsequent to the formation and consolidation of the various beds affected by it; and consequently such dyke could not, we can scarcely conceive, have any influence on the character of the ironstone bed itself, especially as it is not contended, I believe, that such dykes are either of a basaltic or mineral character, there being no appearance, in my judgment, to justify such a conclusion.

*Tubing Bore-holes.*—P. S. Reid having been consulted as to the chance of finding coal in the Cleveland district, at Kirklevington, near Yarm, was afterwards requested to superintend a boring then pursued to the depth of 582½ ft., but which, owing to circumstances which were difficult to determine, had become very expensive, and made slow progress.

The 582½ ft. had been done entirely by manual labour; but Reid recommended the erection of a horse-gin, in which the power was applied to a 40-in. drum placed upon a vertical axle, the arms of which admitted of applying two horses, and men at pleasure, the power gained being in the proportion of one to ten at the starting-point for the horses.

Upon the upright drum a double-ended chain was attached, which worked over sheer-legs erected immediately over the hole, so as to attain an offtake for the rods of 10 fathoms, and so as that, in the act of raising or lowering, there might always be one end of the chain in the bottom, ready to be attached, and expedite the work as much as possible.

These arrangements being made, it was soon found that there was a defect in the tubing which was inserted to the depth of 109 ft., and the defect was so serious, in permitting the sand to descend and be again brought up with the boring-tools, as to render it very difficult to tell in what strata they really were; this increased to such an extent as to cause the silting up of the hole in a single night to the extent of 30 fathoms, and occupied nearly a fortnight in clearing the hole out again.

On carefully examining into this defect, it appeared that the water rose in the hole to the depth of A, Fig. 1098, 74 ft. from the surface; and that at this point it was about level with the high-water mark on the Tees, about two miles distant, which it was no doubt connected with, by means of permeable gravel beds, extending from the arenaceous strata at B, Fig. 1098.

On commencing to bore, the motion of the rods in the hole caused the vibration of the water between A and C at the bottom of the tubing, and so disturbed the quiescent sand as to cause it to run down through the faults in the lower end of the tubing at the latter point.

This tubing was made of galvanized iron plates, riveted together and soldered so as to attempt to make it a water-tight casing; at the top of the hole it was in three concentric circles, which had been screwed and forced down successively until an obstacle was met with at each different place shown by the letters D, E, C. So soon as the outer circle reached the depth of D, all hope appears to have vanished, from those who bored the earlier part of the work, of getting the tube farther; a second tube was, therefore, inserted, which seems to have advanced as far as the point marked E, where it, in its turn, was abandoned; and a third one advanced until it rested in the strata at C, which is, no doubt, the lower part of the lias freestone of a blue nature, as found on the rocks at Seaton Carew, and in the bed of the Leven, near Hutton Rudby. The diameter of the first tubing was 3⅞ in. external and 3½ in. internal; the second tube was 3¼ in. external and 3 in. internal diameter; and the third tube was 2¾ in. external and 2½ in. internal diameter.

Such being the account gathered from the workmen who superintended the earlier part of the boring, it became necessary to decide upon the best course to remedy the evil. At first sight it would have appeared easy enough to have caught the lower end of the tubes by means of a fish-head properly contrived, and thus to have lifted them out of the hole, and replaced them with a perfect tube, such as a gas-tube, with faucet screw-joints; but, on attempting this, it soon became evident that, however perfect the description of tubing which might have been adopted, it would be a work of the greatest difficulty to extract when once it was regularly fixed and jammed into its place by the tenacious clayey strata surrounding it; and that the difficulty of extracting, in the present case, was even enhanced by the inferior quality and make of the tubing: in short, that, unless by crumpling it up in such a manner as to destroy the hole, it was impossible to extract this tubing by main force.

There was, therefore, no other choice left, but to attempt cutting it out, inch by inch; though before doing so, I may add, says Reid, that we did attempt main force, to the extent of upwards of 30 tons, applied to the bottom of the tubing, in which the only success we attained was, the losing of several pieces of steel down the hole, which we were compelled to fish up with a powerful magnet.

After much mature consideration and contrivance, it was determined to order such a perfect tubing as would at the same time present as little obstacle as possible to the clay to be passed through on the outside, as well as surround the largest of the three tubes then in the hole, and present no obstacle to their being withdrawn through its interior.

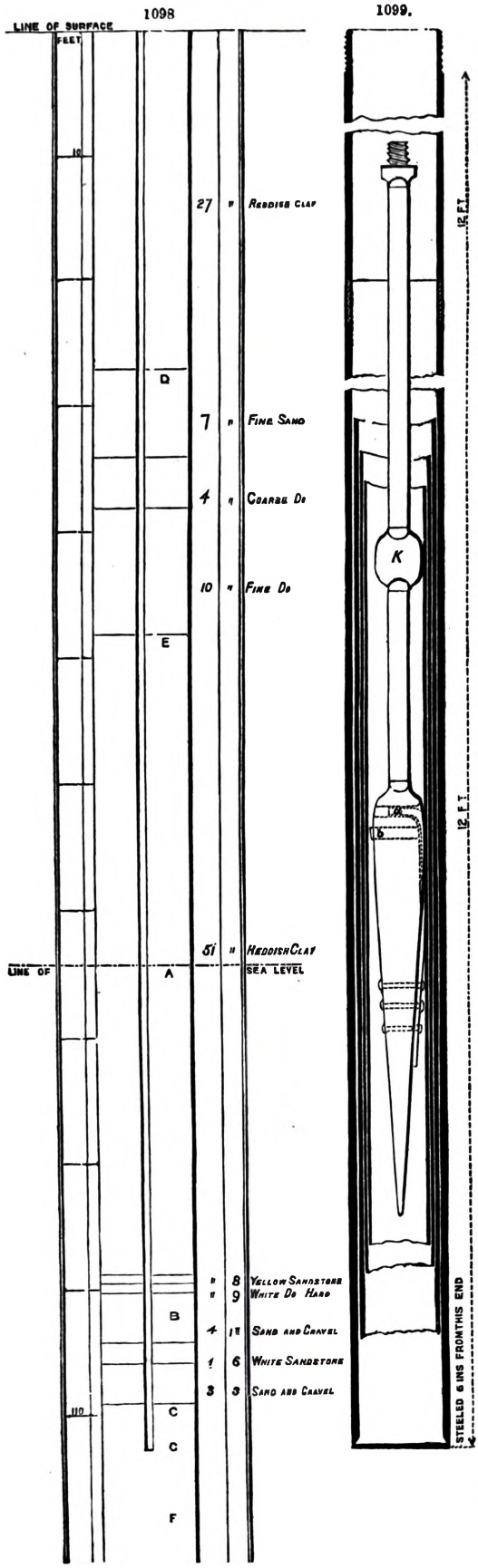
These tubes were made 12 ft. in length, flush outside and in, the lower portion being steeled for 6 in. from the bottom end, so as to cut its way and follow down the space, and cover that exposed by the old tubes when cut and drawn, as shown in Fig. 1099.

In order to commence operations, and avoid too much clay going down to the bottom of the hole, a straw-plug was firmly fixed in the lias portion of the hole at F, Fig. 1098. The lower portion of the new tubes was then screwed on to the top of the old ones by means of powerful clamps, attached to the exterior in such a manner as to avoid injuring the surface; and so soon as it was evident that they could be screwed no farther, the knife or cutter, Figs. 1099 to 1101, was introduced inside the old tubing. Some force, it will be evident, was needed to get this knife down into the tubing, but the spring *a* giving so as to accommodate itself to the hole, permitted its descent to the distance required; this being effected, it was turned round so that the steel cutter, shown at *b*, being forced against the sides of the tube, cut it through in the course of ten minutes or a quarter of an hour's turning. See section at *b*, *c*, Fig. 1101.

The old tubes being three-ply, three of these knives or cutters were required to cut out the three tubes, the inner one being detached first, and then the two exterior ones; and so soon as these latter were cut out as far as they had been forced into the clay, the work became simplified into following down the interior tubing by the new tubes, as shown by the dotted lines from *d* to *e*, until we arrived at the lower end, where it was evident that the old inner tube had been so damaged or torn, either by the putting in or hammering it down, as to leave a vent or fissure for the sand to descend, and thus spoil the whole of the work for all future success in the boring, to say nothing of the very great cost of lifting the sand out, and subsequent most arduous labour to put the hole right.

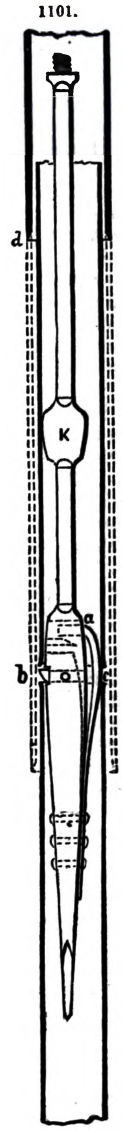
We (says Reid) finally recommenced the boring after about a month's labour in taking out the old tubings, leaving the new ones firmly bedded into the lias formation at G, Fig. 1098, 112 ft. from the surface, and subsequently bored to a depth of 710 ft. in the new red sandstone formation, proceeding at the rate of about 3 ft. in the 12 hours, and leaving the hole so as, if requisite, it may be widened out to 4 in. diameter; and, possibly, should more sand be met with on reaching the magnesian limestone, or sands connected with it, it may again be retubed and the work continued to such depth as may be desirable.

Reid observed, in his paper published in the 'Transactions of the North of England I. M. E.,' "To the care of G. B. Lloyd in the manufacture I attribute a good deal of my success in renewing these tubes. At the same time, the experience so gained in their construction convinces me that if adopted in many places where air-holes are required in mines, and which will not justify the




cost of sinking a pit on a large scale by manual labour, good well-made tubes of this description might, even up to 18 in. diameter, answer as a convenient tubing for air-shaft sides; and the interior could be extracted by boring-tools, similarly to those adopted in *artesian wells* and mines on the Continent, by Kind and Dégousée.

"I am further convinced," remarks Reid, "that in the artesian wells, especially in passing through objectionable springs, the tubes would answer admirably, and that they could, by powerful clamps, be readily forced down, so as to secure a large volume of water from the lower strata, and effectually prevent the injurious mixture of inferior supplies.




"Fig. 1098 shows the geological position of the upper portion of the bore-hole, and the depth to which the imperfect tubing was inserted; it also shows the tidal range, which we were ultimately able to take advantage of, by sinking so as to get 4 fathoms more offtake, and expedite the work; the water

still rising only to A, and flowing always from that point when passed down the hole. Fig. 1099 shows the action of the knife and spring-cutter, when forced down into the tubing, ready to commence cutting. It also shows the lower end of the new tubing enclosing the others at the commencement of the work; the junction of the tubes, by means of the half-lap screw, being shown at *j*. Fig. 1100 shows a front view, with knife or cutter *b*. Fig. 1101 shows the action of the spring and cutter when the requisite length is cut through and ready for lifting; the position of the tube being maintained perpendicular, or nearly so, by the ball or thickening on the rods at K, and the lower end of the tube being supported by the projecting steel cutter at *b*, the dotted lines from *d* to *e* showing the position of the new steel-ended tube when screwed down ready for another operation. In boring deeper after the tubes were removed, three wooden blocks were used round the rods in the new tube to keep them plumb.

"In examining the nature of the strata thus passed through, as described, it will be evident that, to ensure success, the tubing, of whatever it is made, should be as truly cylindrical as possible, straight, and flush surface, both outside and in. It will also be evident that in thus joining pieces of tubing together in this manner, the thickness ought to have a due proportion to the work required, and the force likely to be used in screwing them down; and also that the only correct way of getting such tubes effectively into the ground is by screwing and not hammering, as in the case of pile-driving, or similarly to forcing a nail in. The author has seen this attempted on several occasions, but invariably with failure to the success of the work, and is convinced that no successful practical borer will adopt such measures.

"In some cases we had to widen out holes below the sharp edge of tubing, so as to permit its descent. This is an operation requiring great care and attention." P. S. Reid, in concluding, observed, "That no branch of mine-engineering is qualified to bring out more thoroughly the abilities of a young engineer than a perfect knowledge of the science of boring, requiring, as it does, the best mechanical skill, as well as the best knowledge of assaying rocks by chemical analysis. He is aware of more than one deep boring in important districts, which were finished many years ago, and cost large sums of money, but which, in the then knowledge of chemistry, were not critically examined, and hence, so far as their results are concerned, are utterly useless; the fact being that, beyond the colour of the material bored through, it is unknown whether it was a limestone, or what it was, to this day."

*Rock-boring Machinery.*—In driving a tunnel or quarrying in hard rock, the only method whereby the rock can be worked is by blasting; and the Rock-boring Machine, which we will presently describe, was constructed by George Low for the purpose of boring the blasting holes, with a view to facilitate and expedite the work by superseding the very slow and laborious mode of performing this operation by hand. The machine is driven by compressed air, and works a boring tool or jumper for boring the holes; and the boring-tool works in a direct line, with a self-acting reciprocating motion at a very high velocity, and is continuously turned round during its working, being made to rotate slightly between each blow.

The boring-tool is fixed direct upon the end of the piston-rod of a working cylinder; and this working cylinder moves within another exterior cylinder, in which it is made to rotate for the purpose of giving the rotating motion to the tool. The working cylinder has also a longitudinal forward motion within the exterior cylinder for giving the advancing feed to the tool, the working cylinder being propelled forwards by the compressed air that works the tool, thereby dispensing with the necessity for employing propelling gear, which is liable to break or get out of order, and is subject to rapid wear. The exterior cylinder is carried by a spherical trunnion in a movable radial arm or jib mounted on a travelling carriage, which gives the means of adjusting the boring-tool to any desired direction and position, so that the holes may be bored in the most suitable directions, according to the strata of the rock, for the blasting to take the best effect in breaking up the rock.

This rock-boring machine, which is the invention of G. Low, is shown in Figs. 1102 to 1112. Figs. 1102 to 1106 are sectional plans and longitudinal sections, showing the boring-tool and working cylinder in different positions during the working of the machine; and Figs. 1107 to 1112 are transverse sections at successive points.

The machine is only 4 ft. 6 in. total length, being made as short as possible in order that it may be moved in any direction in the tunnel, so as to enable it to be set to bore at any angle and in any position and direction that may be desired. The working cylinder A, Fig. 1104, constructed of brass, is placed inside an exterior cylinder B of cast iron, which is fitted with a spherical trunnion C to support it in the radial jib or arm of the travelling carriage, as shown in Figs. 1122, 1123. The inner cylinder A is free to move longitudinally within the exterior cylinder from end to end as it advances during the process of boring, as shown in Figs. 1104 and 1106; and it is also free to rotate within the outer cylinder, for giving the rotating motion to the boring tool D. The back end of the working cylinder A is packed with a cupped leather, shown black in Fig. 1106, so as to be air-tight when moving within the exterior cylinder B. The front end of the working cylinder A fits into a wrought-iron cross-head E, in which it is free to revolve; this cross-head is bored out on each side to slide upon the two screwed guide-bars F, which are bolted to the exterior cylinder B, Figs. 1106, 1110, and 1111, and are carried forwards to the end bearing G of the machine. The guide-bars F have a double thread of 1½-in. pitch chased upon them from end to end, but the thread is planed off on the inner side of each screw down to the body of the guide-bar, for the purpose of obtaining greater compactness in the construction of the machine, as seen in the transverse sections, Figs. 1110 to 1112.

At the back end of the working cylinder A is the air-valve N, Figs. 1106 to 1108, which is a circular disc valve with six inlet-ports and six exhaust-ports, as seen in Figs. 1107, 1108. This valve is turned by a double spiral cam O, which is carried forwards into the end of the piston and piston-rod K, and is acted upon by the four rollers P P, Figs. 1106, 1109, bearing on both sides of the spiral wings of the cam. The spiral wings are so sloped that as the piston moves backwards

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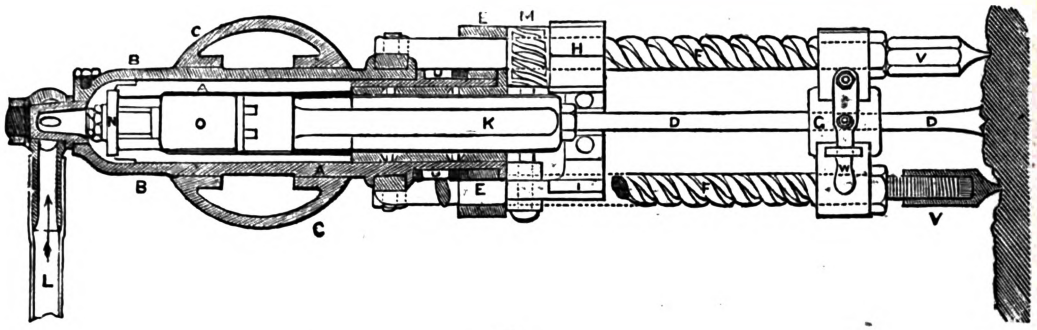


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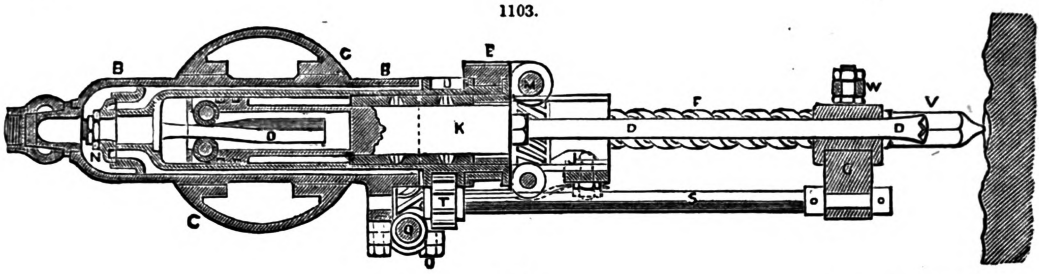


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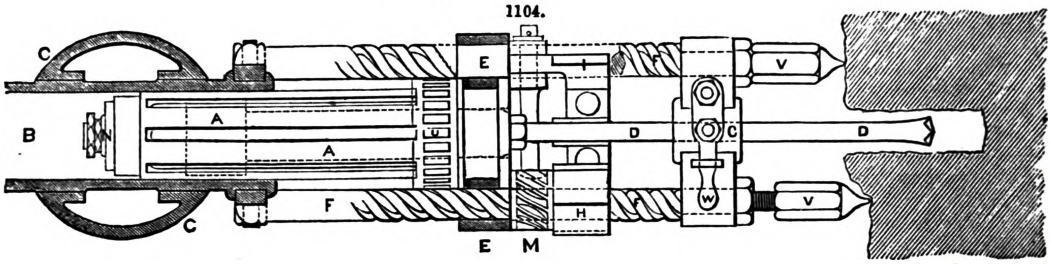


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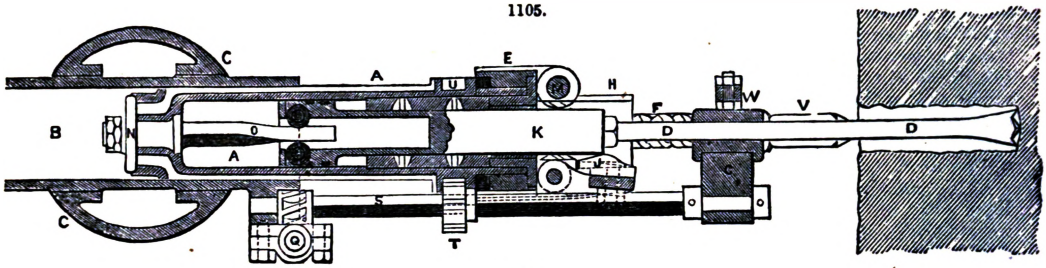


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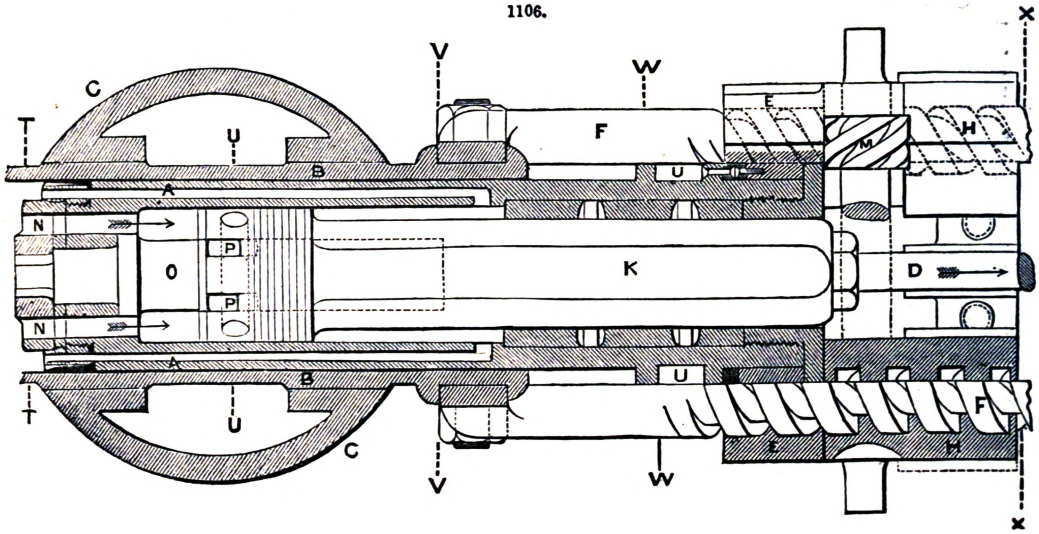

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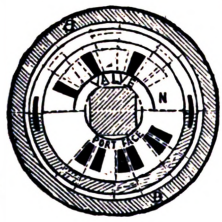


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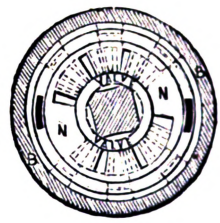


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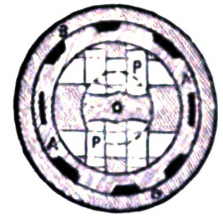


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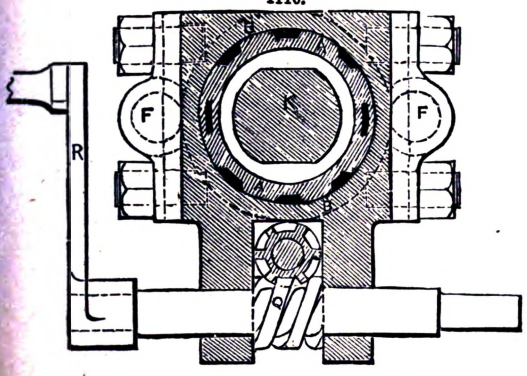


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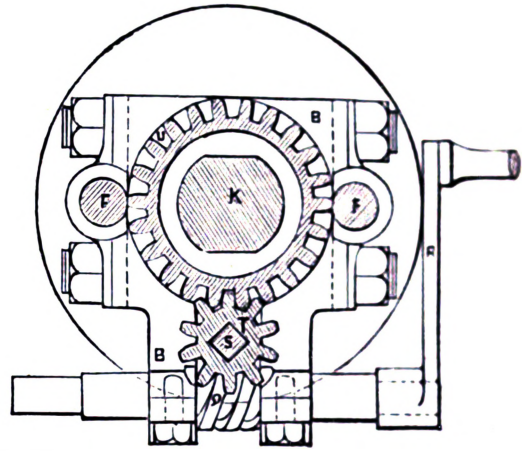



and forwards the cam is gently turned or twisted, carrying with it the air-valve N fixed upon the spindle of the cam. The slopes of the cam are so arranged that the valve N opens the inlet-ports for admitting the compressed air to act upon the large area of the piston, in order to make the forward stroke of the tool; and the valve is then turned so as to allow the air to exhaust again after the piston has struck the blow. The return stroke of the piston is produced by a constant pressure of the compressed air upon the small annular area of the front of the piston, the pressure for this purpose being maintained through the two ports shown in Figs. 1106 to 1110, which are always open. The exhaust air is discharged at the front end of the exterior cylinder B, being carried along grooves in the circumference of the working cylinder A, as seen in the plan, Fig. 1104, and the transverse sections, Figs. 1107 to 1110.

The boring-tool is caused to rotate by rotating the working cylinder A, the piston being prevented from turning in the cylinder by means of two flats planed on opposite sides of the piston-rod K, which fit into corresponding flats in the stuffing-box of the cylinder, as seen in Figs. 1106, 1110, and 1115. The rotating of the working cylinder A, with the piston and boring-tool, is effected by hand by the worm Q, Fig. 1110, which is turned by the handle R, Figs. 1110, 1111, and gears into a worm-wheel fixed on the square shaft S. The brass pinion T, Figs. 1103, 1105, and 1111, slides upon the shaft S, and gears into the teeth U round the circumference of the working cylinder A, Figs. 1104, 1111; so that by turning the handle R the working cylinder is caused to rotate; and as the cylinder advances at each turn of the nuts H, the pinion T slides forwards with it along the square shaft S, as seen in Fig. 1105. In an earlier construction of the boring machine, having a pair of cylindrical trunnions instead of the present spherical bearing C, a self-acting rotating motion was obtained from the spiral cam O that works the disc air-valve N, by prolonging the spindle of the cam through the back end of the exterior cylinder B; and a couple of pawls on the end of the spindle worked into a ratchet-wheel on the end of the square shaft S, which was also prolonged backwards for the purpose in the absence of the spherical bearing C. In practice, however, it has been found preferable to rotate the working cylinder by hand, by means of the handle R, as above described, because the very rapid reciprocation was very severe upon the self-acting rotating motion, making it liable to derangement; and the hand arrangement, besides having the advantage of simplicity, avoids the necessity of prolonging the shaft S backwards, and thus allows of adopting the spherical trunnion C, which gives increased facility for turning the machine into any position desired for boring the holes.

The cross-head E slides forwards along the two screwed bars F as the working cylinder A is advanced inside the exterior cylinder B during the process of boring; and in front of the cross-head the nuts H are fitted on the screwed bars F, against which the cross-head and with it the working cylinder are pressed by the pressure of the compressed air behind the working cylinder A. The nuts H are held from turning, and thereby prevented from going forwards, by four projecting stops upon their circumference, Fig. 1112, which are caught by the catches I below; these catches are kept pressed up by springs against the under-side of the nuts; and between the two

catches is placed a tappet J, so curved that it may be struck by the end of the piston-rod when the latter has reached the outer extremity of its stroke, as shown in Fig. 1105.

The mode of action of this advance motion is as follows:—The compressed air is admitted by the flexible pipe L into the exterior cylinder B behind the back end of the working cylinder A, which is thus kept pressed outwards against the cross-head E, while the cross-head is kept in its place and prevented from going forwards by the nuts H, and these are prevented from turning by the catches I. But when the boring-tool D has advanced $\frac{3}{4}$ in., the distance due to one quarter turn of the nuts H, the outer end of the piston-rod K, which is allowed a range of $\frac{3}{4}$ in. variation in the length of its stroke, strikes against the tappet J, as shown in Fig. 1105, and depresses it sufficiently to make the catches I release the projections on the nuts H; the forward pressure of the working cylinder and cross-head against the nuts then causes them to slip past the catches and advance one quarter turn, thereby moving forwards $\frac{3}{4}$ in. upon the screwed bars F, when the next projections on the circumference of the nuts are caught by the catches I. This process is repeated for every $\frac{3}{4}$ in. bored by the tool, until the nuts reach the front end of the screwed bars F.

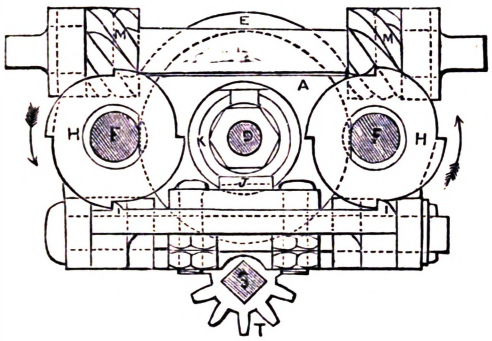
By this arrangement the boring-tool is allowed to advance at whatever rate it may be cutting in the rock. When the rock is comparatively easy to bore and the tool is cutting rapidly, the projections on the nuts slip past the catches from one to another rapidly, and consequently allow each successive $\frac{3}{4}$-in. advance to occur more quickly; whilst when the rock is harder and the tool is cutting slowly, there is so much longer an interval between each release of the catches, and the advance of the nuts is less frequent, thus admitting of a greater number of strokes being made by the boring-tool for each $\frac{3}{4}$-in. length of hole bored.

For winding back the working cylinder A by hand, when required for the purpose of changing the boring-tool, the two worms M M, Fig. 1112, turned by a hand-wheel, are geared into the nuts H, as shown in Figs. 1102 to 1106. The friction of the worms also acts as a break to prevent the nuts from turning too suddenly, as it causes them to move gently when the projections on the nuts are released by the catches I at each $\frac{3}{4}$-in. advance of the boring-tool.

As the working cylinder A and cross-head E only press loosely forwards against the nuts H, neither the nuts nor the screwed bars F receive the slightest portion of the concussion from the blows of the tool; but the shock of each blow is conveyed direct to the air-cushion behind the working cylinder A, in the back end of the exterior cylinder B. This effectually prevents crystallization of the portions that are exposed to the direct concussion of the blow, and prevents any loosening of the several parts of the machine; it also relieves the carriage-frame from the full shock of the blow, and steadies the boring cylinder.

At the outer end of the two guide-bars F are two screwed caps V V with steel points, Figs. 1102, 1104, for the purpose of steadying the end of the machine against the rock. The outer end of the boring-tool D is steadied in the front bearing G, across the end of the two guide-bars F, in order to compel the tool to bore straight when it meets with extra hard rock or quartz veins inclined to the direction of the hole; and by turning the handle W, the top bearing or step can be readily lifted out when the boring-tool requires taking out for changing. During the working of the tool a jet of water is kept constantly playing into the hole; and this, aided by the reciprocation of the tool, effectually clears out all the loose material as fast as it is detached by the tool, without ever requiring the tool to be withdrawn, as in hand-labour, for the purpose of clearing out the hole. In one of these boring machines, worked in the Roundwood Tunnel of the Dublin Corporation Water-works, the water was obtained from the top of the tunnel shaft, being a

1112.

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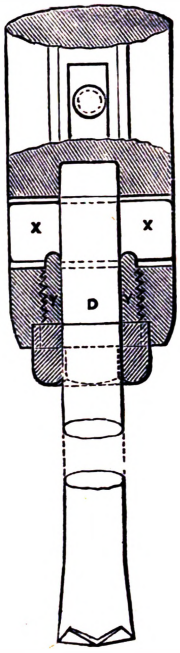


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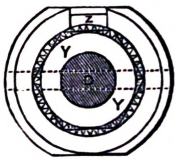


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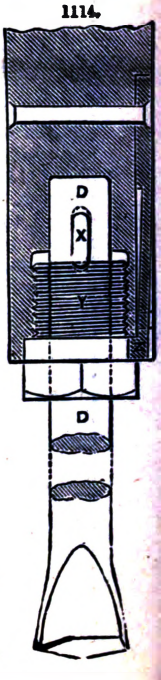



1117.

1118.

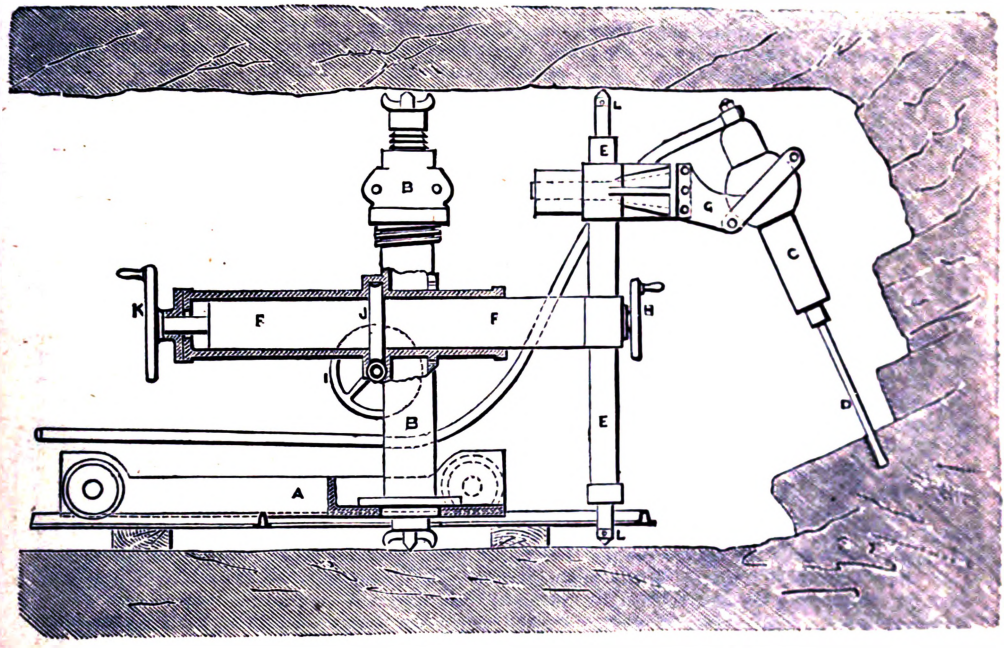
1119

portion of that raised by the pumping engine which drained the tunnel, and the jet was thrown into the bore-hole under a pressure of about 80 lbs. per sq. in.

The mode of fixing the boring-tool D in the piston-rod K is shown in Figs. 1113 to 1115. The fixing of the tool is a very important point in the working of the machine, in order to ensure a thoroughly secure fixing and at the same time the means of readily and quickly changing the tool. The tool D is dropped into a socket in the end of the piston-rod K, and the parallel cotter X being then passed through is fixed by the screwed gland Y, which presses the tool home to the bottom of the socket, and secures the cotter endways by entering into the two notches in the front edge. The gland Y is prevented from turning back by a ratchet and spring Z; and for releasing the tool the spring is held back by a stud while the gland is unscrewed.

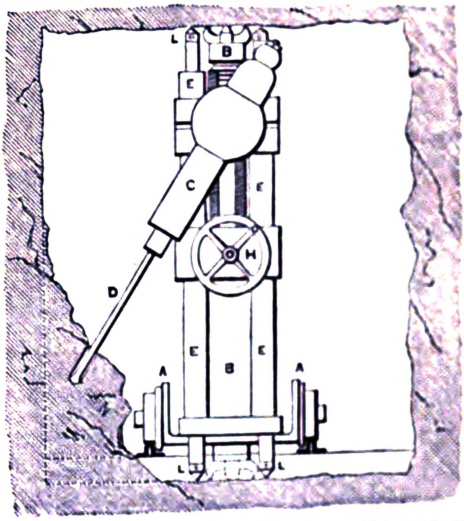
Several different forms of boring-tools have been tried with the machine, but the results of experience have led to the adoption of the two forms only that are shown in Figs. 1113 to 1119. The rose-tool, Figs. 1113, 1117, having two chisel-edges at right angles to one another, is found the best form for commencing the hole and boring the first 9 or 10 in. length. The shape of this tool, in conjunction with the continuous rotary motion given to it between each stroke, prevents

1120.




it from being led away sideways when it meets with a vein of quartz harder than the rest of the rock and lying much inclined to the direction of the hole. The second tool, Figs. 1116, 1118, used for completing the hole, is a chisel formed with the cutting-edge in three bevels a little inclined to one another in both directions. The chisel shown in Figs. 1114, 1119, was found the best for boring straight, but it could not be made to stand well, and was consequently abandoned. A hollow tool has also been tried, into which was inserted a water-jet; and the exhaust air from the cylinder was also turned into it, which blew the water out from the point of the tool into the hole with considerable force. This was found a most excellent plan for keeping the hole clean; but in consequence of its complication and the liability of the jet-orifice to become choked up with deposit from the water employed, it was abandoned, and the separate water-jet already described was substituted.

1121.




The frame and carriage for this boring machine are shown in Figs. 1120, 1121. The traversing carriage A is made very low, in order to allow of readily removing the *débris* from blasting; and upon it is mounted the upright pillar B, capable of swivelling round upon the carriage and having means for clamping it securely between the top and the bottom of the tunnel. The working cylinder C with the boring-tool D is carried by the transverse frame or rest E upon the

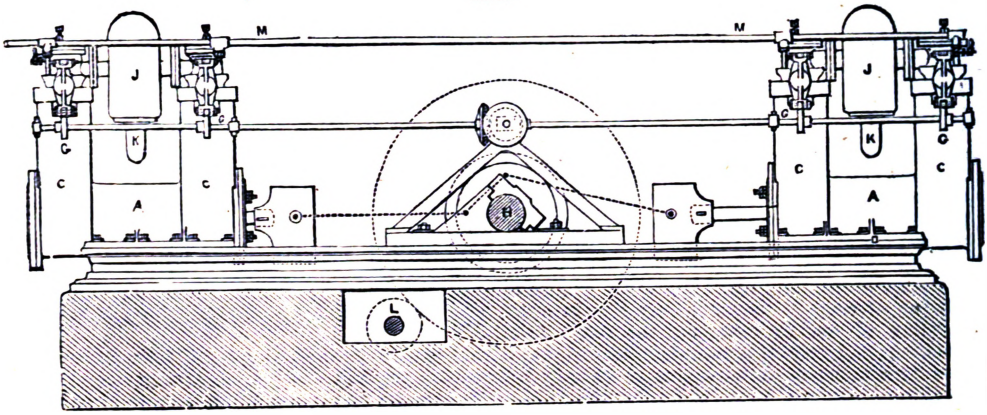
extremity of the horizontal jib F projecting from the centre pillar B. The arm G carrying the boring cylinder C can be traversed into any position in the frame E by means of a screw-motion worked by the hand-wheel H; while the frame E can itself be turned round upon the axis of the horizontal jib F by the hand-wheel I working the worm-wheel J, and the jib F can be lengthened or shortened by the hand-wheel K. By this means the boring cylinder C can be adjusted to any part of the face of the tunnel; and the spherical trunnion by which the boring cylinder is carried in the arm G allows of its being placed to bore in any position and direction. These several adjusting movements enable the tool to bore the holes in the exact line the miners may wish to place the shot, as the boring cylinder can work either upwards, downwards, sideways, or at any inclination; and all the movements are at all times central and within easy reach of the attendant, whatever may be the direction or position of working.

The transverse frame or rest E is provided at each end with a pair of projecting steel points L L, which can be lengthened or shortened so as to clamp the rest securely against the rock, thereby relieving the horizontal jib F and the pillar B from the shocks produced by the blows of the boring-tool. The steel points L L are attached to pistons inside the columns of the rest E; and, by admitting the compressed air between the pistons, the points are caused to strike out against the sides of the tunnel, and are then secured by self-locking catches. It is generally found sufficient, however, simply to wedge the hind wheels of the carriage in order to render the whole perfectly steady, without any necessity for clamping the carriage and rest against the rock.

The compressed air for working the boring machine is supplied by an Air-compressing Engine at the top of the shaft, driven by a small portable steam-engine. The air-compressing engine is shown in Figs. 1122 to 1126, and consists of two horizontal compressing cylinders A A, Fig. 1122, fitted with air-tight pistons packed with brass rings or cupped leathers, Fig. 1124. On each end of the cylinder A are upright chambers C C, and on the top of each chamber are a pair of inlet and delivery air-valves, so that there are two inlet-valves D D and two delivery-valves E E to each compressing cylinder; these valves are circular, and fit air-tight upon conical faces, as seen in Figs. 1124, 1125. The four inlet-valves D D are each suspended from a lever F, and in the original construction there was simply a weight on the outer end of the lever to cause the valve to shut when the piston B had drawn in sufficient air to fill the chamber C; it was found, however, that the valves did not work very steadily with the levers and weights, and they also shut before the piston reached the end of the stroke, so that part of the stroke was wasted in uselessly expanding the air in the chamber C. A cam G, Fig. 1125, worked from the crank-shaft H, was therefore added to each of the valve-levers F; and the cam opens the inlet-valve at the commencement of each forward or suction stroke of the piston, and keeps it open till the commencement of the return or compressing stroke, when the valve is shut suddenly by the weight; and this arrangement has proved quite satisfactory. The delivery-valves E E are shut by the back-pressure, as soon as the compressed air is all forced out of the chambers C; they deliver the air into the air-vessels J, which are for the purpose of equalizing the pressure of the air under the varying pressure of the stroke. A pipe K from each of the two air-vessels conveys the compressed air to a large wrought-iron receiver, from which it is supplied for working the boring machine.

The two air-compressing cylinders A A, Figs. 1122, 1124, are each 14 in. diameter with 18 in. length of stroke, and are placed at each end of a cast-iron bed-plate; the pistons are worked by connecting-rods from the double cranks H at right angles to each other, which receive motion from the countershaft L driven by the steam-engine. By employing two cylinders of half area each for compressing the air, worked by cranks at right angles to each other, instead of a single larger cylinder, an advantage is gained in delivering the compressed air to the receiver more uniformly, and also the strain on the working parts is more evenly divided. The cylinders A are filled with water, which rises at each stroke to the top of the upright chambers C C, and the surplus water is forced through the delivery-valves E, the object being to fill up every space with water at the end of the stroke, and so ensure every particle of air being forced through the delivery-valves. To allow for leakage and waste of water, a supply is kept constantly flowing into the inlet-valves D from the small pipe M, regulated by a tap; and the water forced through the delivery-valves at each stroke keeps the air-vessels J J constantly filled with water up to the mouth of the pipe K, so that the compressed air is kept quite cool. The surplus water passing into the pipe K, slowly accumulates in the large air-receiver, out of which it is discharged occasionally

1122.



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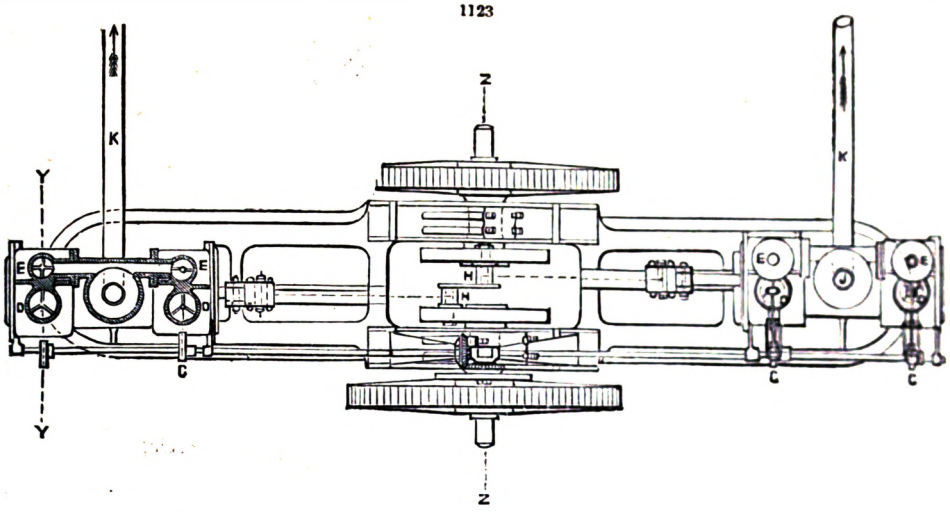


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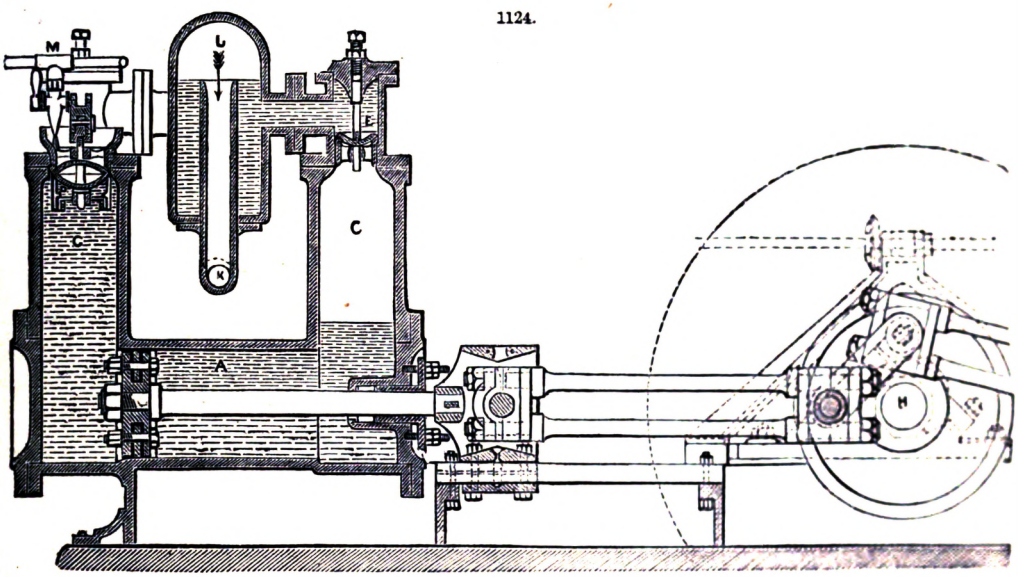
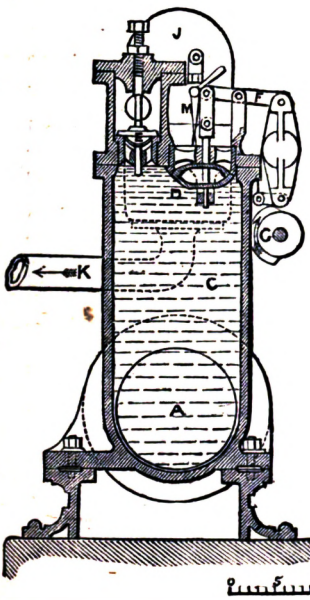
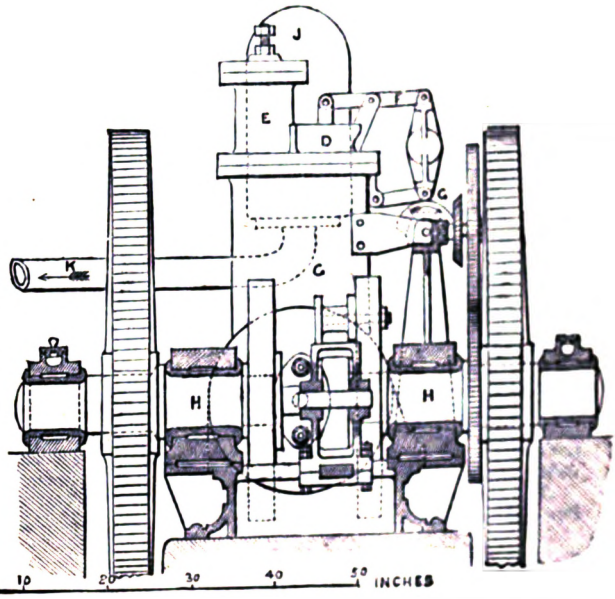



1125.




1126.



The crank-shaft H is driven at 22 revolutions a minute, and at each stroke the piston draws in the air through the inlet-valve at one end of the cylinder, and compresses the air to six atmospheres, or 90 lbs. the sq. in., at the other end of the cylinder, discharging the compressed air through the delivery-valve to the receiver. The minimum pressure maintained in the air-receiver is 75 lbs. the sq. in., and the maximum 125 lbs., the average being about 85 lbs. the sq. in. From the receiver the compressed air is conveyed, by cast-iron pipes with india-rubber joints, up to within 50 ft. of the boring machine. It is then conveyed to the machine through an india-rubber pipe made with six-ply canvas, and about 100 ft. long, which allows the boring machine to be advanced or drawn back without undoing a single joint.

This boring machine, of which a longitudinal and transverse section are shown in Figs. 1120, 1121, was employed in the construction of the Roundwood Tunnel for the Dublin Corporation Water-works, where it bored the holes for blasting at one of the working faces. The tunnel is rectangular, 5 ft. wide and 6 ft. high, and is carried through Cambrian rock of a remarkably hard and difficult character, interspersed with quartz veins. Six shot holes of 20 in. depth were usually fired at each blast, and these six holes of $1\frac{3}{4}$ in. diameter were all bored by the machine in about $3\frac{1}{2}$ hours; two chisels were used for each hole, which required fresh grinding before being again used. With hand-work, however, each of the same holes takes $2\frac{1}{2}$ to 3 hours for drilling, and requires usually about fifteen fresh tools before it can be completed. The practical value of this remarkable saving of time that is effected by the use of the machine is specially experienced in such work as tunnelling or other rock-blasting, where saving of time is of such great importance both in expediting and economizing the work. The average rate at which the very hard rock was bored by the machine at the Roundwood Tunnel was about 1 in. a minute; and it has been found as the result of experience with the machine that it bores quicker and keeps the edge on the tool better by striking with less force of blow but with greater rapidity. The number of blows has been increased from 250 to 500 or 600 blows a minute, and the result is that one hole is now bored with two tools without re-sharpening, instead of using five or six tools, as formerly; and with one tool a hole of 26 in. depth was bored in the Dalkey granite without re-sharpening.

The following are the results of working in the Dalkey granite:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1st hole, | $24\frac{1}{2}$ | inches deep, | in | 11 | minutes | 10 | seconds. |
| 2nd | „ | $19\frac{1}{2}$ | „ | „ | 14 | „ | .. | „ |
| 3rd | „ | 9 | „ | „ | 5 | „ | 55 | „ |
| 4th | „ | $4\frac{1}{2}$ | „ | „ | 2 | „ | 10 | „ |
| 5th | „ | 9 | „ | „ | 7 | „ | 35 | „ |
| 6th | „ | 9 | „ | „ | 5 | „ | 25 | „ |

The following are the results of working in the remarkably hard rock of the tunnel at Roundwood, Wicklow:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1st hole .. | $8\frac{1}{2}$ | inches depth, | in | $3\frac{1}{2}$ | minutes. |
| | 6 | „ | „ | 8 | „ |
| | 9 | „ | „ | 3 | „ |
| Total .. | $23\frac{1}{2}$ | „ | „ | $14\frac{1}{2}$ | „ |
| 2nd hole .. | 12 | „ | „ | 8 | „ |
| | 9 | „ | „ | 4 | „ |
| Total .. | 21 | „ | „ | 12 | „ |
| 3rd hole .. | 6 | „ | „ | 5 | „ |
| | 9 | „ | „ | 10 | „ |
| Total .. | 15 | „ | „ | 15 | „ |
| 4th hole .. | 10 | inches depth, | in | 6 | minutes. |
| | 9 | „ | „ | 3 | „ |
| Total .. | 19 | „ | „ | 9 | „ |
| 5th hole .. | $10\frac{1}{2}$ | „ | „ | 4 | „ |
| | 8 | „ | „ | $4\frac{1}{2}$ | „ |
| Total .. | $18\frac{1}{2}$ | „ | „ | $8\frac{1}{2}$ | „ |
| 6th hole .. | 14 | „ | „ | 10 | „ |

The average at which the machine continued to bore was, for the first portion of the hole, 10 and 11 in. depth in $4\frac{1}{2}$ to 8 minutes; and for the second portion, 9 and $9\frac{1}{2}$ in. depth in 3 to $3\frac{1}{2}$ minutes.

The following special points of advantage have been experienced in this boring machine; and these may be considered as essential conditions to be fulfilled in a good machine for the purpose of boring in hard descriptions of rock, and for standing satisfactorily the special wear and tear to which such machines are necessarily subjected.

The boring part of the machine with the tool is made very short, so as to allow it to work in any direction and position in the tunnel, in order that the blast of the hole bored may displace the largest amount of rock. The carriage-frame carrying the working cylinder is also very compact, occupying little space, and allowing the cylinder to be quickly adjusted into any desired position.

The reciprocating parts are very few in number, and are in the direct line of the blow; these are only the piston and rod in one piece of steel, and the tool secured in the piston-rod so as to allow no play. Moreover, in order to prevent crystallization of the parts exposed to the direct concussion, a cushion of air is provided at the back of the working cylinder, which also relieves the carriage-frame from the shocks of the blows. Also, the tool being made to reciprocate with the piston, the hole is more easily kept free from the *débris* than when the tool is stationary and receives blows from a detached piston, as in other descriptions of boring machines; and the strong water-jet playing into the hole is found to keep it quite clear during the process of boring.

The advance of the tool is self-acting, and exactly at the same rate that the tool is cutting, however variable may be the nature of the rock; and whether the tool is cutting at the rate of

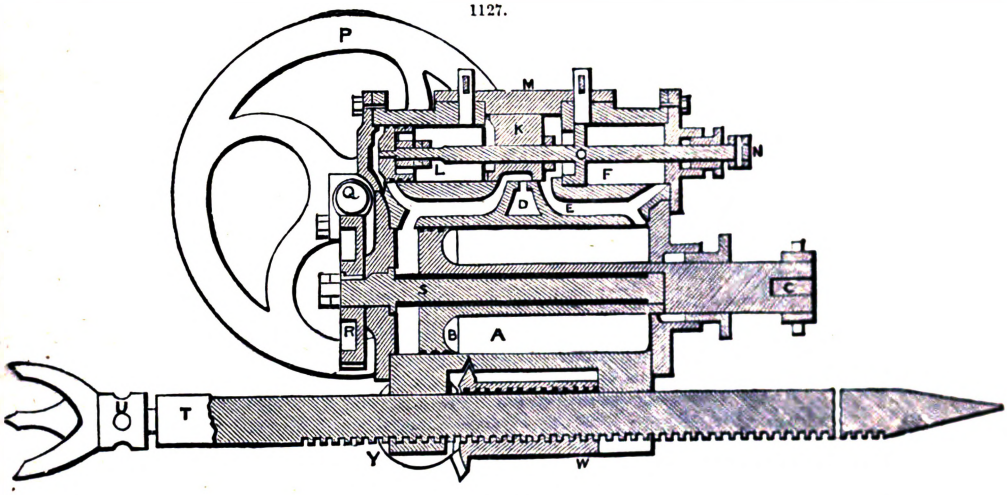
3 in. a minute in one part of the hole, or only 1 in. a minute in another part, the advance given to the tool is exactly at the same rate that the boring progresses in each case; so that there is no risk of the piston at any time working beyond its proper range of stroke, and striking the clyinder-cover. The advance motion for the tool is obtained from the pressure that drives the piston, without the use of propelling gear, the absence of which greatly increases the durability of the machine. The turning motion for the tool also, being connected to the stationary outer cylinder, is freed from the source of derangement that would arise from the rapidity of the blows of the tool if the turning motion were connected to the reciprocating part. The motion for working the valve is gradual and easy in its action, so that a very rapid action is obtained without any destructive shocks. The outer end of the tool is guided in a bearing, to prevent it from working to one side, and getting jammed when meeting with an oblique vein of harder material.

The machine is arranged so that it can be brought to work again immediately after a set of holes have been blasted and before the *débris* is removed, which can be done whilst the machine is at work, the material being carried or thrown through the clear space left by the carriage-frame; and a jet of air being left open near the face at the time of explosion soon dilutes and clears off the gases resulting from the explosion of the powder. This saves much of the loss of time which occurs with other machines in removing the *débris* before the machine can be set to work again. The compressed air, on being discharged from the boring cylinder, also serves effectively to ventilate the workings, and supplies fresh air to the miners.

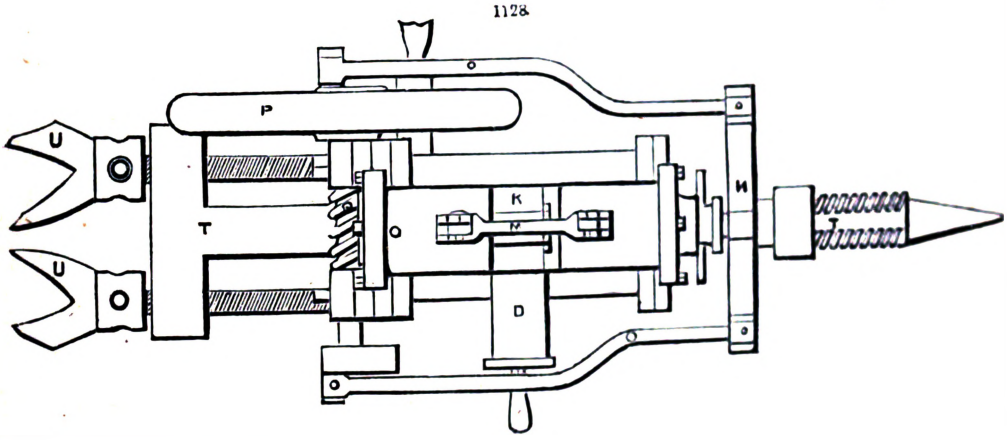
*Bergstræm's Boring Machine.*—This boring machine, Figs. 1127 to 1132, which is now being used at the Perseberg mines, near the town of Philipstad, in Sweden, is a modification of that constructed by Schumann, of Freiberg.

The machine consists of a cast-iron cylinder A, Fig. 1127, 4½ in. in diameter, in which the piston B, and at the same time the borer fixed in the socket C, is moved by compressed air. The length of the stroke is 7 in. The compressed air enters by a pipe at D, and then passes through one of the ports E into the cylinder, and moves the piston backwards and forwards. F and F are two single-acting cylinders, in which the pistons O L, and their common piston-rod, are moved by air. K is the slide-valve, which is pushed backwards and forwards by bosses on the piston-rod, in order to make the air act sometimes on one side of the piston and sometimes on the other. By means of the nuts at L, the position of the slide-valve on the valve-face is determined, and con

1127.




1128.

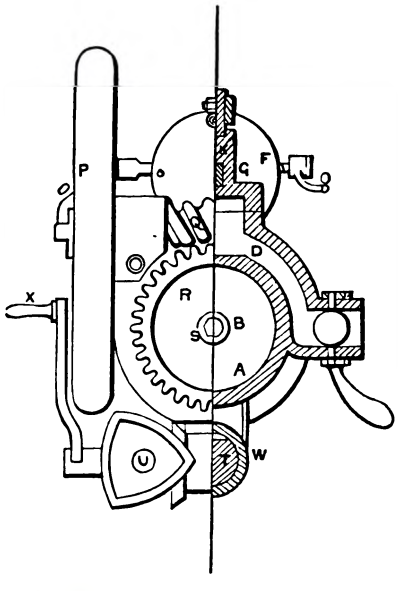


sequently at the same time the entry of the air. M is a guide for the slide-valve. On the valve-rod the cross-head N is keyed, which, by means of two connecting-rods o, sets in motion the fly-wheel P, its axle, and the worm Q, which has been formed on it. The screw takes into the worm-wheel R, which thus causes the spindle S to rotate. The spindle S has on each side a groove, in which feathers, dovetailed into the hollow piston-rod C, can readily move, and thus when the spindle turns it causes the rotation of the piston and consequently also of the borer.

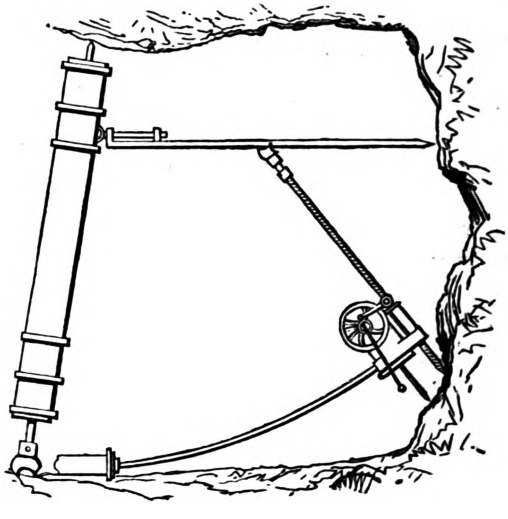
The machine hangs from, or may be supported by, a bar T having a thread cut on it. In order to prevent the machine from turning on the bar T, the thread is cut away, as shown on the cross-section and plan. By means of the screws U and U, the rod is firmly forced against the rock. The advance of the machine is effected by hand, by working a winch-handle X, which actuates a mitre-wheel Y, which gears into another mitre-wheel on the nut W. This nut W is held between two lugs cast on the cylinder, and therefore as the nut is caused to rotate the machine advances or retires. The machine gives 200 to 300 and even 350 blows a minute, and the borer makes one entire turn for 22 blows.

*Strut.*—In order to furnish a point of support for the screws U, a wooden strut, Fig. 1130, provided with an iron at its upper end and at its lower with an adjustable screw and tripod, is firmly fixed across the level.

1129.




1130.



It will now be readily understood that the machine can be fixed in any position, and consequently holes can be bored in all directions. It takes two men to put up the machine, and one to attend to it. The other man can be boring by hand in the meantime.

*Air-compressor.*—At the Perseberg mines the machine is worked by compressed air. The air-compressor, Figs. 1131, 1132, was designed by Professor Angström. It consists of two vertical iron barrels, 15½ in. in diameter and about 8 ft. high, communicating with one another at the bottom by a chamber.

The upper end of each barrel is provided with a valve-box having two valves, one opening inwards, for the admission of air, and the other outwards into the delivery-box, for the eduction of air. In one barrel a piston is made to work up and down, and in order to deliver every particle of air at each stroke, and to keep the barrels cool, a quantity of water is placed inside the pump, which at each stroke entirely fills up the valve-box, and thus expels the whole of the air from the pump. The other barrel has no piston working in it, but is also filled with water, which is caused to rise and fall as the piston goes down and up. This water also forces out all the air from the barrel and valve-box at each stroke. The piston-rod is connected to the main rod of the pumping engine, and is provided with a cross-head, from which a weight is suspended by rods. The stroke is 7 ft. Four strokes a minute furnish enough air for one boring machine. The air must be compressed to 15 lbs. or 20 lbs. a sq. in., which corresponds to an excess pressure of 1 or 1½ atmosphere. If such a pressure cannot be had, no good results are obtained.

This air-compressor is specially constructed for places where the power is derived from the main rod of the pumps. It is considered that 5 or 6 horse-power would be required to drive an air-compressor. In the Perseberg adit the air-compressor is from 60 to 70 fathoms from the end; there is no regulator.

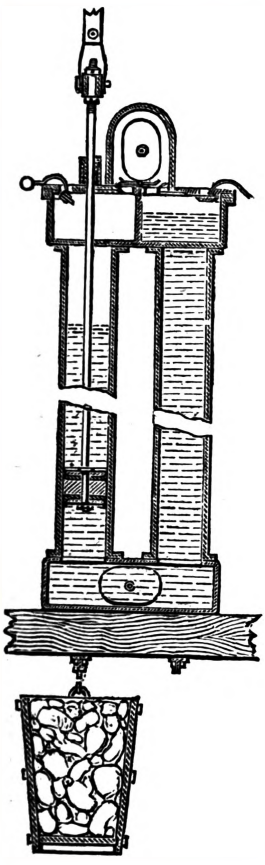
*Pipes.*—The air is conducted from the compressor along the level by cast-iron flange-pipes, 4 in. in diameter and 9 ft. long, with a small spigot and socket, the joints being made with tar, mixed with finely-powdered brick and lime.

These pipes conduct the air very nearly to the end, and the air is finally brought into the machine by some 30 ft. of india-rubber pipe, 3 in. in diameter and $\frac{5}{16}$ in. thick.

F. B. Doering's rock-boring machine, Figs. 1133 to 1138, has an effective means of regulating

the forward movement of the main cylinder in which the piston carrying the tool works, as the work progresses. A piston-valve *a* regulates the supply of water or other fluid to and its outlet from a pair of cylinders *b b*, attached to the main cylinder *c*, the valve *a* being worked by a piston in a cylinder by motive fluid distributed from the main cylinder to the small cylinder *d*, the piston of which is connected to the valve. Instead of attaching the adjacent cylinders to the boring

1131.



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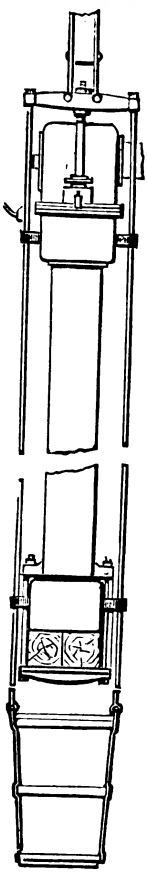

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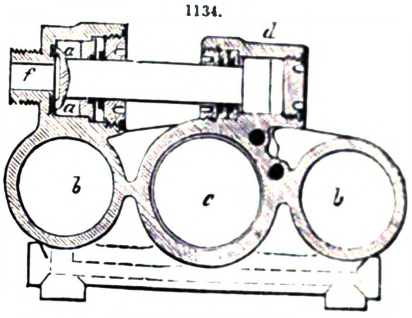


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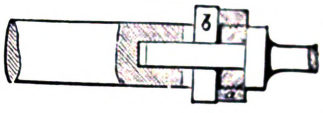


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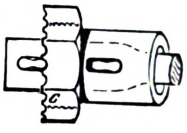


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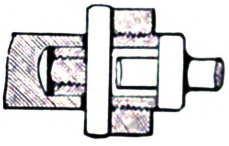

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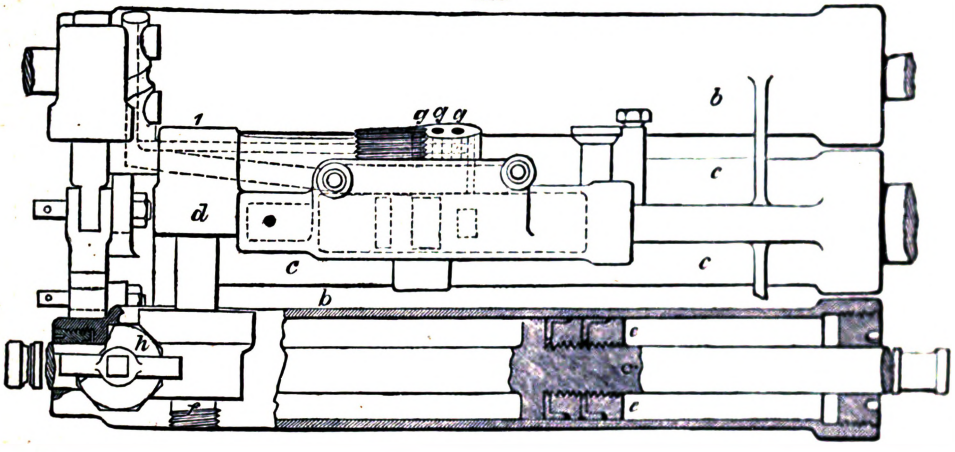



cylinder, the pistons of these cylinders may be attached to the working or boring cylinder, the adjacent cylinder in this case being fixed. The adjacent cylinders *b b* have each a fixed piston *c*, and a supply of compressed air may be maintained at the front. So much of each of the cylinders as is behind the piston or pistons is filled with water. A tube connected at *f* leads from the piston-valve *a* to a reservoir containing this water or fluid.

The action of the engine is as follows:—Supposing the main cylinder *c* and adjacent cylin-

ders *b b* are at the back end of their travel; whenever the tool, as it continues to work, has cut to a sufficient depth to allow the main piston to uncover a port in the main cylinder communicating with the cylinder of the piston-valve *a*, this valve moves and allows part of the water in the adjacent cylinders *b b* to escape under the pressure of the compressed air on the other side of the fixed pistons *e e*, or under the pressure due to the weight of the machine if the same is working downwards. The adjacent cylinders and main cylinders are thus caused to advance, and this advance takes place intermittently, according to the quantity of water which escapes from the valve, until they reach the forward end of their travel. A cock at the front part of the adjacent cylinders is then opened to let out the compressed air, and pressure is exerted on the water in the reservoir to force the water through the valve into the adjacent cylinders, the small cylinder *d* exhausting into the main cylinder to allow the valve *a* to be moved by the pressure of the water, the piston of the main cylinder being put into the required position. The pressure of the water in the adjacent cylinders causes them and the main cylinder *c* to run back on their supporting-bars to recommence their forward travel; the valve *a* is then closed, the cock at the front end of the adjacent cylinders reversed, and the pressure in the water reservoir removed.

When the engine is working vertically or nearly so, the employment of compressed air in the adjacent cylinders may be dispensed with, as the weight of the engine will be sufficient to effect the feed as the tool cuts. Again, instead of compressed air in the adjacent cylinders, a vacuum may be created in the water reservoir connected with the valve. This application of water to regulate the advance of a boring engine may be applied directly to the advance of the boring-tool, as shown in Fig. 1137, the cylinder *a* being stationary, and the piston-rod *b* forming a cylinder in which a piston *c* attached to the boring-tool moves. Water is placed in the front portion of the piston-rod at *f*, and a pressure of the motive fluid acting on the back of the piston being constantly supplied through *h* to keep it pressed against the water so as to advance when the water or a portion of it is discharged through *k*. In this case, the valve for the discharge is formed by the piston. This discharge can only take place when the tool has penetrated to such a depth as to allow the port *k* to communicate with *m*. A circular groove is cut in the piston at *k* to regulate or adjust the engine for working in materials of different hardness or softness.

The ports *g g g*, Fig. 1133, in the main cylinder are formed at various distances from the cylinder end, and communicate with the passage leading to the advance cylinder *d* through a cock common to all these ports. According to whether the material operated upon necessitates a short or long stroke, the cock is turned to open the way between the advance cylinder and one or other of the ports, to produce the advance of the engine when the main piston has passed this port in its stroke. Instead of employing a cock common to all these ports, the inventor has provided plugs by which he can close all the ports except the one required for work. It is also sometimes desirable to alter the position of the ports in the main cylinder for working the valve; this may be effected by a cock *h* arranged similarly to that before described, or the communication between the cylinder and its valve-piston may be throttled or *wire-drawn*.

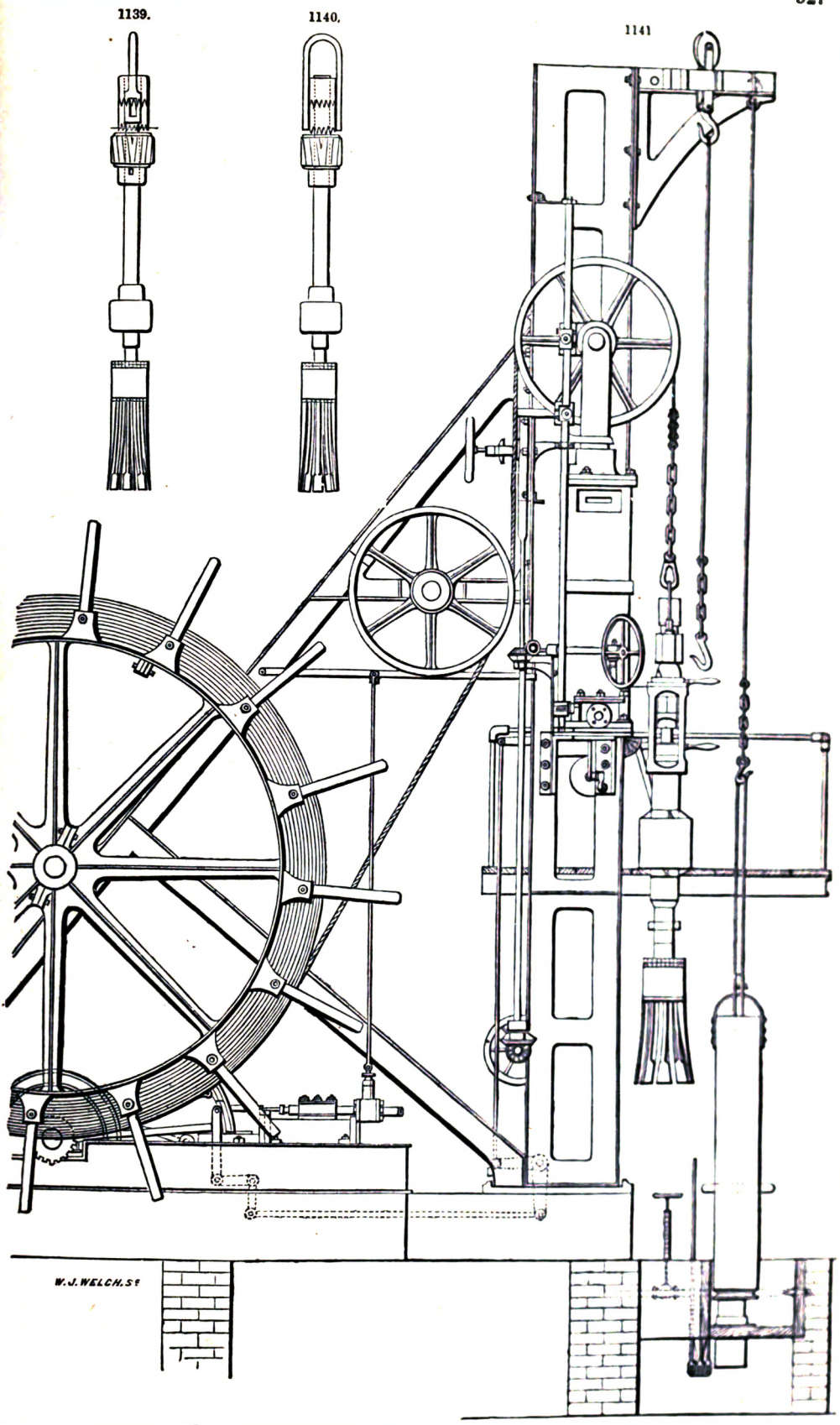
For the purpose of securing the tool in the end of the piston-rod, Doering threads the end of the piston-rod to receive a nut *a*, Fig. 1135, and makes the position of the ordinary key *b* adjustable. The nut *a* is screwed up and the key driven in, thus enabling him to dispense with the washers usually employed. In some cases grooves *c*, Fig. 1136, are formed in the nut to keep it from turning. A nut is also employed on the inner end of the tool-head, Fig. 1138, and the main piston-rod formed hollow so as to pass the tool down it and secure it by a nut and key, as in Fig. 1135.

*Mather and Platt's Boring Machine.*—The construction of the boring-head and shell-pump, and the mode of acquiring the percussive motion, constitute the chief novelties of the system and machine, shown in Figs. 1139 to 1142. The couple-cylinder engine, with the reversing or link motion, is used for winding and lowering the apparatus; but an ordinary winding engine, similar to those used in collieries, may be applied.

The boring-head consists of a wrought-iron bar, about 8 ft. long, on the lower part of which is fitted a block of cast iron, in which the chisels or cutters are firmly secured. Above the chisels an iron casting is fixed to the bar, by which the boring-head is kept steady and perpendicular in the hole. A mechanical arrangement is provided, by which the boring-head is compelled to move round a part of a revolution at each stroke. The loop or link by which the boring apparatus is attached to the flat wire rope is secured to a loose casting on the wrought-iron bar, with liberty to move up and down about 6 in. A part of this casting is of square section, but twisted about one-fourth of the circumference. This twisted part moves through a socket of corresponding form on the upper part of a box, in which is placed a series of ratchets and catches, by which the rotary motion is produced. Two objects are here accomplished—one the rotary motion given to the boring-head, the other a facility for the rope to descend after the boring-head has struck, and so prevent any slack taking place, which would cause the rope to dangle against the side of the hole, and become seriously injured by chafing.

The shell-pump, Fig. 1141, is a cylinder of cast iron, to the top of which is attached a wrought-iron guide. The cylinder is fitted with a bucket similar to that of a common lifting pump, with an india-rubber valve. At the bottom of the cylinder is a clack, which also acts on the same principle as that in a common lifting pump, but it is slightly modified to suit the particular purpose to which it is here applied. The bottom clack is not fastened to the cylinder, but works in a frame attached to a rod which passes through the bucket, and through a wrought-iron guide at the top of the cylinder, and is kept in its place by a cotter, which passes through a proper slot at the top of the rod. The pump-rod, or that by which the bucket is worked, is made of a forked form, for the twofold purpose of allowing the rod to which the bottom clack is attached to pass through the bucket, and also to serve as the link or loop by which the whole is suspended.

The wrought-iron guide is secured to the top of the cylinder, and prevents the bucket from


1139.
1140.
1141
W. J. WELCH, Sc

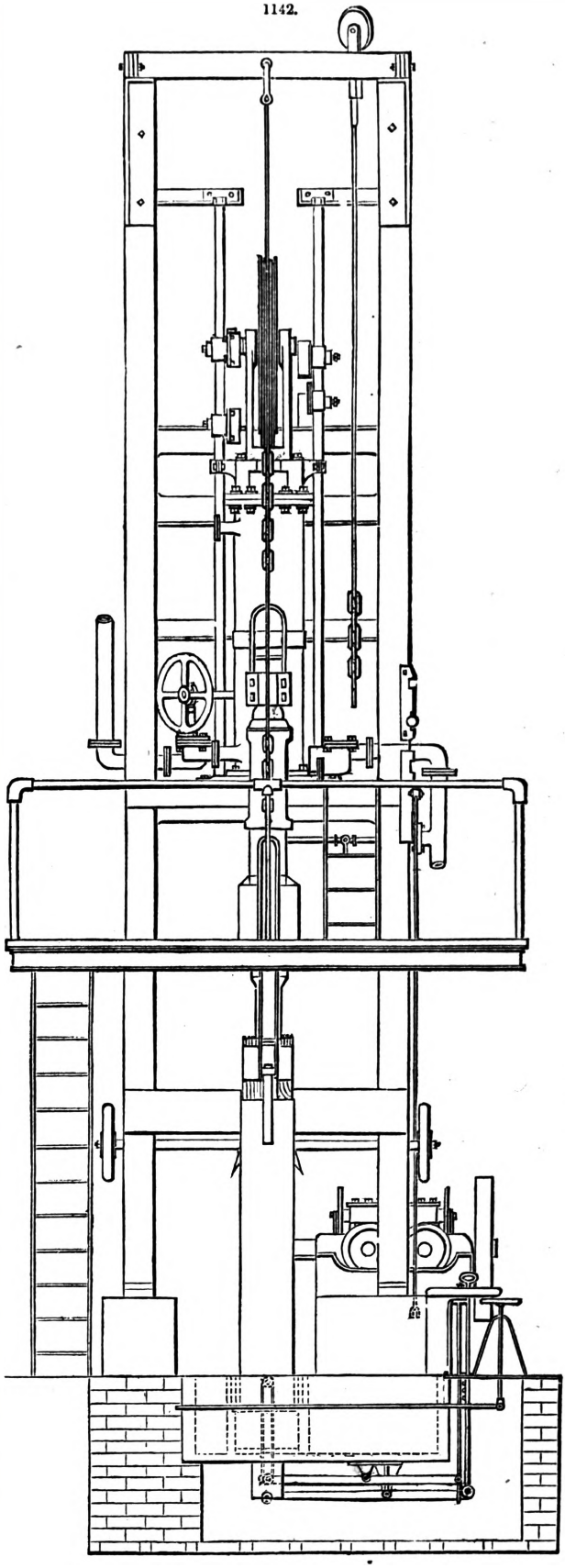
being drawn out when the whole is so suspended. The bottom clack also is so arranged that it is at liberty to rise about 6 in. from its seating, so as to allow large fragments of rock, or other material, to have free access to the interior of the cylinder when a partial vacuum is formed there by the up-stroke of the pump.

The percussive motion is produced by means of a steam-cylinder, which is fitted with a piston of 15 in. diameter, having a rod of cast iron 7 in. square, branching off to a fork, in which is a pulley of about 3 ft. in diameter, of sufficient breadth for the rope to pass over, and with flanges to keep it in its place. As the boring-head and piston will both fall by their own weight when the steam is shut off and the exhaust-valve opened, the steam is admitted only at the bottom of the cylinder; the exhaust-port is a few inches higher than the steam-port, so that there is always an elastic cushion of steam of that thickness for the piston to fall upon.

The valves are opened and shut by a self-acting motion derived from the action of the piston itself; and as it is of course necessary that motion should be given to it before such a result can ensue, a small jet of steam is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the rope, and allow it to receive the weight of the boring-rod by degrees, and without a jerk. An arm which is attached to the piston-rod then comes in contact with a clam, which opens the steam-valve, and the piston moves quickly to the top of the stroke. Another clam, worked by the same arm, then shuts off the steam, and the exhaust-valve is opened by a corresponding arrangement on the other side of the piston-rod. By moving the clams, the length of the stroke can be varied at the will of the operator, according to the material to be bored through. The fall of the boring-head and piston can also be regulated by a weighted valve on the exhaust-pipe, so as to descend slowly or quickly, as may be required.

The general arrangement of the new machine may be described as follows:—The winding-drum is 10 ft. in diameter, and is capable of holding 3000 ft. of flat wire rope, $4\frac{1}{2}$ in. broad and $\frac{1}{2}$ in. thick; from the drum the rope passes under a guide-pulley, through a *clam*, and over the pulley which is supported on the fork end of the piston-rod, and so to the end which receives the boring-head, which being hooked on and lowered to the bottom, the rope is gripped by the clam. A

1142.



small jet of steam is then turned on, causing the piston to rise slowly until the arm moves the clam, and gives the full charge of steam; an accelerated motion is then given to the piston, raising the boring-head the required height, when the steam is shut off, and the exhaust-valve opened in the way described, thus effecting one stroke of the boring-head as regulated by a back-pressure valve in the exhaust-pipe. The exhaust-port is 6 in. from the bottom of the cylinder; when the piston descends to this point it rests on a cushion of steam, which prevents any concussion. To increase the lift of the boring-head, or compensate for the elasticity of the rope, which is found to be 1 in. in 100 ft., it is simply necessary to raise the clams on the clam-shaft whilst the percussive motion is in operation. The *clam* which grips the rope is fixed to a slide and screw, by which means the rope can be given out as required. When this operation is completed, and the strata cut up by a succession of strokes thus effected, the steam is shut off from the percussive cylinder, the rope unclamped, the winding engine put in motion, and the boring-head brought up and slung from an overhead suspension-bar by a hook fitted with a roller to traverse the bar. The shell-pump, Fig. 1141, is then lowered, and the *débris* pumped into it, by lowering and raising the bucket about three times, which the reversing motion of the winding engine readily admits of; it is then brought to surface and emptied by the following very simple arrangement. At a point in the suspension-bar a hook is fixed perpendicularly over a small table in the waste tank, which table is raised and lowered by a screw. The pump being suspended from the hook hangs directly over the table, which is then raised by the screw till it receives the weight of the pump. A *cotter*, which keeps the clack in its place, is then knocked out, and the table screwed down. The bottom clack and the frame descending with it, the contents of the pump are washed out by the rush of water contained in the pump-cylinder. The table is again raised by the screw, and the clack resumes its proper position; the *cotter* is then driven into the *slot*, and the pump is again ready to be lowered into the hole as before. It is generally necessary for the pump to descend three times, in order to remove all the *débris* broken up by the boring-head at one operation.

The following facts obtained from the use of the machine in boring in the new red sandstone at Manchester, will show its actual performance, and enable us to compare it with the other systems. The boring-head is lowered at the rate of 500 ft. a minute; the percussive motion is performed at the rate of 24 blows a minute, and being continued for ten minutes, the cutters in that time penetrate from 5 to 6 in.; it is then wound up at 300 ft. a minute. The shell-pump is then lowered at the rate of 500 ft. a minute, the pumping continued for one minute and a half, and being charged, the pump is wound up at 300 ft. a minute. It is then emptied and the operation repeated, which can be accomplished three times in ten minutes, at a depth of 200 ft. The whole of one operation, resulting in the deepening of the hole 5 to 6 in., and cleansing it of *débris* ready for the cutters or boring-head being again introduced, is seen to occupy an interval of 20 minutes only.

*Blasting.*—Gunpowder is the most valuable agent for excavation; it is, however, of more service in the work of extraction than in that of preparation, because in removing the minerals those regular forms of the walls are not required which distinguish the shaft and the drift from the gallery. Blasting-powder is employed in different quantities and in various forms, according to circumstances. In slaty open rock, in rotten brittle shale, and in loose gravel, it is of no use; but in hard rock, in sandstone, limestone, and similar substances, blasting is extremely serviceable, and often reduces the prices of working hard rock to that of soft material. Gunpowder is of most service where the vein has a seam of soft mineral, or a succession of cavities on one side, so that a blast applied at the opposite termination of the vein may remove the whole thickness of it. If the soft matter or the cavities are in the middle of the vein, it requires always two blasts, and of course the drilling of two holes, as well as two charges of gunpowder, to remove the vein. The amount of gunpowder used is often calculated to be proportionate to the amount of rock removed, but this is not so in practice; where the amount of matter removed is limited, the consumption of powder increases more rapidly than the quantity of rock removed. In mines which have a large quantity of shattered rocks, the application of powder is limited by the consideration that injury may be caused to other parts of the mine. The removal of thick veins, or masses, of heavy rock, also veins of pyrites, is often conducted with considerable difficulty, because heavy blasts cannot conveniently be applied. In all such cases it is, however, the cheapest way of working masses; and if holes for blasting cannot well be drilled, they can be formed by acids. Pyrites may be penetrated by nitric or muriatic acid; also native metals, such as copper, limestone, and magnetic iron ore, may be dissolved by any acid—the muriatic is, however, the most generally used. In this case we cannot sink any other form of hole than a vertical one. The manipulation is easily performed by setting a glass tube vertically upon the rock, and providing its top with a funnel and apparatus, so as to let in the acid drop by drop. If the pipe is close fitting to the rock, and the acid poured in very slowly, the hole will not be much larger than the glass-pipe. The tube must descend with the bottom of the hole, and be always close to it. This operation works very slowly; but in pyrites, or compact magnetic iron ore which cannot be penetrated by steel tools, it is a useful method of preparing a hole for blasting. When heavy masses are to be detached by one charge, the hole may be made wider in the bottom by letting down the acid more rapidly, which will spread over a larger surface and dissolve a greater width. See GUNPOWDER.

We will now give one example of firing charges of gunpowder by means of a fuze, and another by a voltaic battery.

*Demolition of a Fort at Furruckabad, in January*, 1858: *by P. H. Scratchley, R.E.*—The fort ordered to be destroyed was a front built of good sound brick masonry, consisting of two solid towers, the left one being 54 ft. in height and the other 36 ft. high, and both being 54 ft. in diameter, connected by a revetted curtain 130 ft. long and 34 ft. in height; two portions of revetment, 30 ft. in length, running at right angles to the curtain, from the towers on each side, and of nearly the same height as the curtain; and also a wall 160 ft. long, 11 ft. high, and 2 ft. thick, forming part of an enclosed court-yard. L is put = the length of the line of least resistance in feet.

The project for the demolition of the front was as follows:—Two charges, with lines of least resistance 18 ft. long, to be placed in each of the towers, 3 ft. in advance of their centres, and at one-lined intervals, Figs. 1143 to 1148. Two charges, with L = 12 ft., to be placed in each tower

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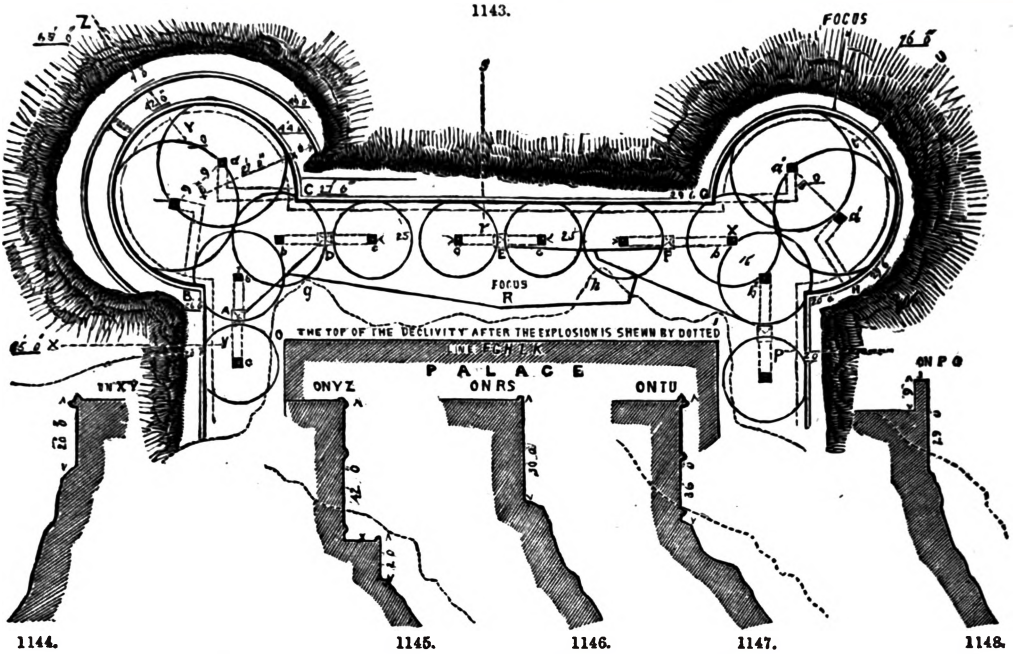


1144. 1145. 1146. 1147. 1148.

in rear of the angles formed by the tower and the revetment. The remaining portion of the connecting-curtain to be destroyed by charges, with L = 10 ft., placed at 2½-lined intervals, which required 6 more, as shown in Fig. 1143.

In the towers, galleries with returns were to be driven at nearly equal levels, which the nature of the ground favoured. The mines in the revetment were to be formed by sinking 5 shafts, each 15 ft. deep, with galleries running out right and left from them to the requisite distances.

The charges were calculated according to the formula for strong masonry revetments without counterforts, placed at two-lined intervals, or $\frac{3}{20}$ $L^3$. As native powder was to be used, there was allowed $\frac{1}{5}$ of $\frac{3}{20}$ $L^3$, or $\frac{3}{100}$ $L^3$, in addition to the proper charges of English powder, making the formula $\frac{3}{20}$ $L^3 + \frac{3}{100}$ $L^3 = \frac{18}{100}$ $L^3$.

Scratchley was also directed to prepare the towers at the entrance gateway for demolition, and he carried out the following plan. These towers were 28 ft. in diameter, and from 22 ft. to 29 ft. high on the outside: they were built of softer masonry than the others, and were solid only to a height of 15 ft. from the bottom. A shaft was to be sunk in the centre of each tower, at the level of the ground inside (15 ft. from the bottom), 12 ft. deep; and small galleries were to be driven right and left, 5 and 6 ft. long respectively. The charges were calculated, as above, by the formula $\frac{18}{100}$ $L^3$, and were to be placed so that their lines of least resistance were respectively 8 and 9 ft. long.

The following journal gives the particulars of the work executed.

A detail of officers and men of the Engineer Brigade left the camp at Futtehghur at 3 P.M., 5th January, 1858:—

| Corps. | Officers. | Native Officers. | Sergeants. | Corporals. | Privates. | Bugler. | Total. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| Royal Engineers | 3 | .. | 2 | 5 | 52 | 1 | 63 | Lieut. Scratchley, R.E. |
| Bengal Engineers | 2 | .. | .. | .. | .. | .. | 2 | „ Wynne, R.E.<br>„ Keith, R.E. |
| Bengal Sappers and Miners .. | .. | 2 | 4 | .. | 33 | .. | 39 | „ Lang, B.E.<br>„ Forbes, B.E. |
| Total .. .. | 5 | 2 | 6 | 5 | 85 | 1 | 104 | |

This detail was divided into 3 reliefs, namely:—

1st relief—20 rank and file, European.
12 „ Native.
2nd relief—19 „ European.
12 „ Native.
3rd relief—18 „ European.
12 „ Native.

The 1st relief commenced work at 8 P.M. on the evening of January 5th.

*January 5th, 1st Relief*, 8 till 12 P.M., Wynne.—4 galleries, marked B, C, G, H, Fig. 1143, were commenced in the towers, at the respective levels of 26 ft. 6 in., 27 ft. 6 in., 29 ft. 6 in., and 29 ft. 6 in., below the terreplein of the fort, and driven towards the centre of each tower. 4 shafts, A, D, E, F, were also commenced at a distance of 10 ft. from the curtain wall.

*January 6th, 2nd Relief*, 12 till 4 A.M., Keith.—Shafts A, D, E, F, were completed to the depth of 15 ft. each, and were made 4 ft. by 3 ft. Galleries running parallel to the wall were commenced right and left of each shaft. Soil very easy, being made earth. Galleries B, C, G, progressed slowly through very tough pucka masonry. That at H was softer.

*3rd Relief*, 4 till 8 A.M., Lang.—The 8 galleries of A, D, E, F, progressed rapidly through made earth. The galleries B, C, G, advanced through tough masonry, and H through soft masonry. The tools were in bad order and were not adapted to mining.

*1st Relief*, 8 till 12 A.M., Forbes.—The 8 galleries progressed rapidly. The gallery H was cut through pucka masonry, 7 ft., and reached rubble. The progress at B, C, G, was slower

*2nd Relief*, 12 till 4 P.M., Wynne.—The 8 galleries were nearly finished:—

| | | | Ft. | In. | |
|---|---|---|---|---|---|
| That at | B | had advanced | 9 | 0 | through pucka masonry. |
| „ | C | „ | 8 | 6 | „ |
| „ | G | „ | 3 | 0 | „ |
| „ | H | „ | 12 | 0 | through made earth. |

*3rd Relief*, 4 to 8 P.M., Keith.—The galleries of A, D, E, F, were finished to the following lengths:—

| | Ft. | In. | | Ft. | In. |
|---|---|---|---|---|---|
| A *c* (Fig. 1143) .. | 12 | 0 | E *c'* (Fig. 1143) .. | 12 | 6 |
| A *b* „ .. | 13 | 6 | E *c* „ .. | 12 | 6 |
| D $b^1$ „ .. | 14 | 0 | F *c* „ .. | 12 | 6 |
| D *c* „ .. | 12 | 6 | F $b^1$ „ .. | 20 | 0 |

Hardly any progress was made at G.

*1st Relief*, 8 till 12 P.M., Lang.—Another shaft I, Fig. 1143, was commenced at a distance of 10 ft. from the wall. A party was also employed in lodging charges in the wall to be destroyed, described in accompanying memorandum.

*January 7th, 2nd Relief*, 12 P.M. till 4 A.M., Forbes.—

B gallery was 24 ft. long.
C „ 24 „
H „ 17 ft. 10 in., and return commenced.
G had not extended through pucka masonry.

*3rd Relief*, 4 till 8 A.M., Wynne.—Shaft I was completed to a depth of 15 ft., and 2 galleries were commenced from it, running right and left parallel to the wall.

*1st Relief*, Keith.—The galleries of shaft I were completed to the required lengths, namely, *b*, 14 ft., and *c*, 12 ft. Chambers were formed in all the shaft-galleries.

B gallery was completed, with a return 5 ft. 8 in. long.
C „ „ „ 7 ft. long.
At G the work was continued by blasting.
H gallery was completed, with a return 6 ft. long.

*2nd Relief*, 12 till 4 P.M., Lang.—The chambers in all the galleries except G were completed. G was 8 ft. 5 in. long, pucka masonry 7 ft. thick having been cut through. More experiments were made on the wall of the court-yard.

*3rd Relief*, 4 till 8 P.M., Forbes.—More charges were tried on the wall, and a party was employed destroying it by hand.

*1st Relief*, 8 till 12 P.M., Wynne.—Shafts A and B were sunk 12 ft. deep in the entrance towers.

*January 8th, 2nd Relief*, 12 till 4 A.M., Keith.—Galleries were driven from shafts A and B, right and left, 7 ft. and 9 ft. long respectively.

*3rd Relief*, 4 till 8 A.M., Lang.—A party of men was employed in demolishing the wall. Chambers were prepared and bamboos laid (as in all the other mines) for the entrance-tower mines. The whole of the mines were now ready for loading, but the powder had not yet arrived

*9th January.*—At 3 P.M. this afternoon the party of Engineers, after carefully closing all the openings of the shafts and galleries, was marched back to Futtehghur camp.

*Remarks.*—The whole of the work had thus been carried on without interruption, the soil being very easily worked, and being evidently all made earth. No sheeting had been required, excepting in the left gallery at the right entrance tower, where the earth fell in. The whole of the mines were ready for charging *in forty-eight hours*, with the exception of that in gallery G, where the pucka masonry gave great trouble. The dimensions of all the galleries were 3 ft. 6 in. by 2 ft. 6 in.

*13th January.*—A detail of the Engineer Brigade left camp at 5.30 A.M. to load the mines at the Fort, namely, 2 officers, 2 sergeants, and 82 rank and file; and 1 officer, and 24 native sappers. 12 of the sappers were, however, afterwards withdrawn to be employed elsewhere.

The charges were placed as follows:—

| | | | | | |
|---|---|---|---|---|---|
| In B gallery at | $a^1$ | .. .. | 1050 | lbs. | of Native powder. |
| C „ | *a* | .. .. | 800 | „ | English „ |
| | | | 99 | „ | Native „ |
| G „ | *a* | .. .. | 874 | „ | English „ |
| H „ | *a'* | .. .. | 1050 | „ | Native „ |

| | | | | | | |
|---|---|---|---|---|---|---|
| A shaft at | $c$ | .. .. | 180 lbs. | of Native | powder. | |
| | $b$ | .. .. | 310 | „ | „ | „ |
| D „ | $b^1$ | .. .. | 310 | „ | „ | „ |
| | $c$ | .. .. | 180 | „ | „ | „ |
| E „ | $c'$ | .. .. | 180 | „ | „ | „ |
| | $c$ | .. .. | 180 | „ | „ | „ |
| F „ | $c$ | .. .. | 180 | „ | „ | „ |
| | $b^1$ | .. .. | 258 | „ | English | „ |
| I „ | $b^2$ | .. .. | 258 | „ | „ | „ |
| | $c$ | .. .. | 180 | „ | Native | „ |

*Approximation.*—For English powder and length of 16 ft. of least resistance, we have 16 cubed = 4096, and $\frac{3}{20}$ of 4096 = 614 lbs. of gunpowder, which may be put = 620, the half of which is 310 lbs.

The charges were placed in boxes where practicable, the hose was laid in bamboos, and the whole was carefully tamped.

The galleries took most time in loading and tamping, and were not ready till 7 P.M., whilst the shafts were finished by 4 P.M.

The firing was put off till the next morning, when the hoses of all the shafts were brought to one focus R. There was one focus for each tower, the length of hose for each being 5 ft. less than that for the upper focus, to allow, if possible, a few seconds elapsing between the two explosions. The hose was lighted at the three foci at the same time, at the sound of the bugle, and the explosions were very nearly simultaneous, with the exception of that of one mine, marked X, Fig. 1143, which did not take place till 30 seconds after the others.

The demolition was complete, and the object desired was attained, which was to leave a pretty practicable ramp from the outside into the interior.

There is no doubt that if more time had been allowed, or more men had been procurable, the demolition might have been effected by the expenditure of one-half of the quantity of powder used; but it must be borne in mind that Scratchley's instructions were to have everything ready *in forty-eight hours*, and native powder was to be had in abundance.

The mines at the entrance gateway were not loaded, but remained ready to be charged at some future time.

*Statement of the Expenditure of Powder, Hose, &c.*

| | | | | | |
|---|---|---|---|---|---|
| 2 | charges of | 1050 lbs. | each, total | 2100 lbs., | Native powder. |
| 1 | „ | 874 / 800 | „ „ | 1674 lbs., | English „ |
| 1 | „ | 99 | „ „ | 99 lbs., | Native „ |
| 6 | „ | 180 | „ „ | 1080 lbs., | „ „ |
| 2 | „ | 310 | „ „ | 620 lbs., | „ „ |
| 2 | „ | 258 | „ „ | 516 lbs., | English „ |

Total, 2190 lbs. of English powder.
„ 3899 lbs. of Native „
„ 848 feet of ½-inch hose.
„ 2 port-fires.

Taking the line of least resistance = 18 ft., then 18 cubed = 5832, and $\frac{18}{100}$ of 5832 = 1050 lbs. of powder nearly. The other charges were calculated in a similar manner.

*Memorandum.—Partial Destruction of a Wall by means of Small Charges.*—This wall was 11 ft. high, 2 ft. thick, and about 160 ft. long. There were two piers, 6 ft. square, one on each side of an entrance at the centre of the wall; these were built much better than the remainder of the wall, which had been constructed with bricks and a little mud, mortar being found only in the foundation.

Ten charges, of 5 lbs. each, were placed along the wall, at intervals of 10 ft., and were lodged as nearly as possible 2 ft. below the surface of the ground, and under the centre line of the wall. One charge of 10 lbs. was placed in each pier, 2 ft. 6 in. below the level of the ground, and under its centre.

The piers were completely thrown down, without violence: all the other charges, with the exception of three, failed; some blowing out the tamping and making a small breach in the wall, others throwing out the foundation and earth on the other side, but failing to bring down the wall, or any part of it. Four more charges, of 5 lbs. each, were placed equidistant between the former, which completely destroyed the part where they were lodged.

The remainder of the wall was picked and thrown down by about twelve men in a very short time, and other portions of the walls around were thrown down in the same manner.

The powder made use of was native, and undoubtedly of inferior strength to that of European manufacture.

Blasting was not tried, as the nature of the wall did not admit of it. Had Scratchley known that it was so very rotten, he would have had the whole of it picked down.—'*Papers of the Corps of Royal Engineers*,' vol. viii.

Bickford's fuze is generally employed in blasting operations. See FUZE-MAKING MACHINE.

*Blasting with Large Charges of Gunpowder at Holyhead*, 1860: *by Col. Hamilton, R.E.*—The quarries, opened and worked for the harbour-works, were situated on the declivity of the Holyhead Mountain, at about 1500 yds. distance from and in rear of the land end of the breakwater; the portion thereof, 120 ft. by 40 ft., and 90 ft. in height, on this occasion operated on, was formed of quartzose schist, extremely hard, and weighing about 1⅓ cwt. to the cubic foot, stratified in lines extending from N.E. to S.W., a little overhanging to S.E., but nearly vertical, with numerous joints in that and other directions throughout the whole mass.

An entrance gallery, Figs. 1149, 1150, 5 ft. 6 in. by 3 ft. 6 in., was driven from the face of the rock, commencing at a height of 12 ft. above its base, with a view to gain an efficient line of tamping resistance, a favourable joint in the line of strata having been taken advantage of to the extent of 34 ft., where a shaft, 3 ft. 6 in. by 3 ft. 6 in., was sunk to the depth of 14 ft. 6 in.; from this, level galleries, 5 ft. 6 in. by 3 ft. 6 in., were driven right and left, the former to the extent of 49 ft. 9 in., and the latter 56 ft. 6 in., with a length of 43 ft. 6 in. of headings and chambers of similar dimensions, as illustrated in the accompanying plan and elevation. The galleries, shafts, and so on, were worked out by blasting, necessitated by the hard nature of the rock; and the increased size given to these communications above that generally adopted was with a view to enable the miners to strike with more freedom and effect, the extra excavation being more than compensated by the facility of working. The chambers were formed by slightly enlarging the short return-headings, and were placed from 2 to 3 ft. below the level of the ground or rail line in front of the quarries, to ensure the bottoms of the face acted upon being well lifted, as want of attention to this particular before a former explosion led to considerable subsequent labour in removing a portion of stone left standing.

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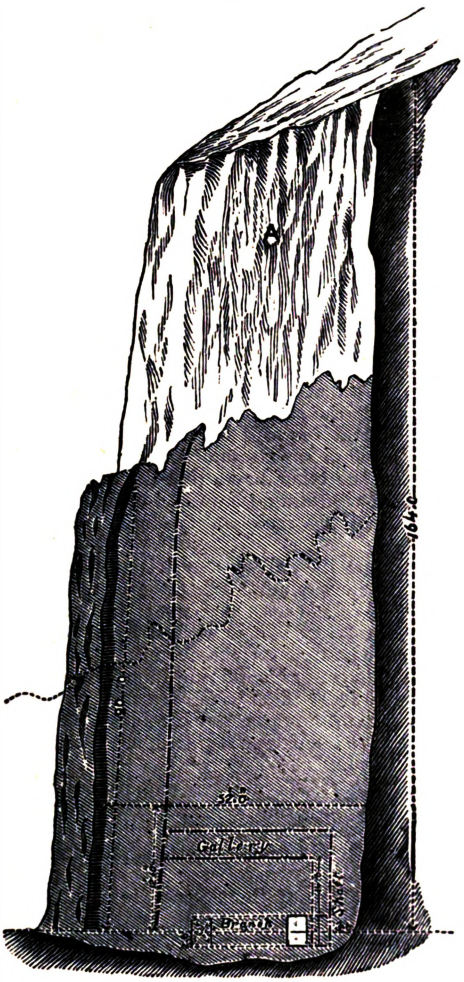

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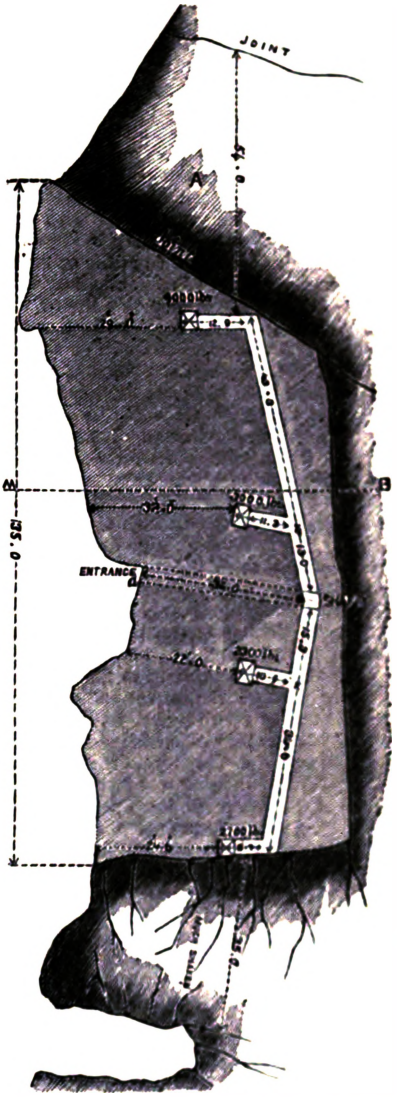



The gunpowder used was similar to the fine grain Government powder, its strength having been previously tested by projecting with a 1½-oz. charge a 68-lb. shot, from a mortar at an angle of 45°, to the distance of 480 ft.; the charges were placed in canvas bags well coated with tar, 2000 or 3000 lbs. in one bag, and the remainder in smaller bags, and so respectively lodged in each chamber.

The tamping was executed throughout with a sort of stiff red clay obtained in the vicinity, used in a slightly moist state, well rammed up to the entrances of the chambers, and close to the bags of gunpowder, merely leaving a small air space round the latter, and was continued

to the mouth of the gallery in the face of the rock: it apparently answered its intended purpose admirably.

The battery employed to fire the charges was that known as Grove's. It had 32 cells, and platinum plates, 8 in. by 6 in., in nitric acid, in porous cells surrounded by diluted (6 to 1) sulphuric acid; it was placed on the top of the cliff, and directly in rear of the line of chambers, 300 ft. distant from the upper edge of the former; two copper wires connected the battery with each charge, extending from the latter through the galleries directly up the face of the cliff and on to the cells, where the four positive were united, as well as the four negative. To the extremities of the copper wires at the charges were attached platinum wire about ¼ in. in length, protected by a wooden block, round which block a small bag of fine or sporting powder was tied and introduced into the large bags of powder before mentioned.

The total quantity of powder used in the explosion was 12,000 lbs., placed in four charges, amounting respectively to 4000, 3000, 2300, and 2700 lbs., with lines of least resistance 29 ft., 32 ft., 22 ft., and 24 ft. 6 in., as shown in Figs. 1149, 1150; these respective charges were not calculated by any specific formula founded on the lengths of the lines of least resistance, but a certain number of pounds of gunpowder a ton of rock to be removed was allowed, according to the particular features and tenacity of the portion to be acted on (in the present instance 1 lb. of gunpowder to 3 tons of rock); this calculation was based upon the experience gained from numerous previous explosions of a similar character carried out at different parts of the quarries. In some cases, 1 lb. of gunpowder was found sufficient to remove only 2 tons, in other cases it has proved adequate to displace 4 tons of stone.

Shortly after the hour appointed (twelve o'clock), the mines were fired on a signal with most successful results; the rock a little above its base was seen to bulge slightly outwards, and then tumble to pieces, emitting much smoke, and the superincumbent mass gently sliding down, separated into various sized blocks; a perfect volley of small stuff, mostly the tamping, shot horizontally along, close to the ground, directly in front of the face of rock, to a distance of about 250 ft., covering the surface with a coating of fine damp clay, separated into small particles like sand; no stones of any magnitude were thrown out beyond the general *débris*, which was confined to a width of 125 ft. from the original face of the quarry.

The total quantity of rock removed was about 40,000 tons, which gives 3⅓ tons to the pound of gunpowder used. The report on the effect of a similar explosion in January, 1857, shows that 7½ tons the pound of gunpowder were then brought down, or nearly double the quantity removed by each pound on this occasion; and on reference to the accompanying plan it will be observed that if, instead of the charge of 4000 lbs., a smaller one had been employed, the effect would probably still have extended as far as the joint at that end, and also that a slight addition to the charge of 2700 lbs. at the other end would have caused the fall of all the portion as far as the recess, which is described as much shaken. It may also be remarked that the cliff brought down in January, 1857, was 25 ft. higher than that here described; also that the strata of the former were horizontal, whilst those of the latter were vertical; and, on the other hand, that the blocks forming the *débris* of the latter were smaller, and more suitable for building, than those of the former; it is evidently, therefore, difficult to fix any rules for determining the quantity of powder required, especially where hidden joints exist which limit its effects.

The miners were but little impeded by wet or damp; the gallery was driven with a slight inclination upwards to allow any water met with to find its way out. Whenever damp holes had to be fired, pitched bags or cases, capable of holding 3 to 5 oz. charges, were used; the smoke from the firing of the blasts and foul air were removed by a rotatory blower worked by a boy at the mouth of the heading, and a canvas pipe conveyed the fresh air to the chambers.

The powder was brought to the mouth of the gallery in casks (containing from 50 to 100 lbs.), and there emptied into canvas bags capable of holding 50 lbs.; these bags were then passed from hand to hand by men placed at intervals in the galleries, to the respective chambers, where they were discharged into larger bags previously lodged there, to the extent required, after which some old powder-cask sackings were thrown round and over them.

The clay for tamping was brought to the mouth of the main gallery in wagons, and wheeled through it on planks to the shaft, where it was thrown down, and conveyed from the bottom thereof in a similar manner to the headings. This method was found to require less time and labour than any other known to the engineer. The whole of the tamping was performed in 42 hours by 25 labourers.

The copper wires leading from each charge were, throughout their course in the tamping, lapped round with calico and tar-bands, great care having been taken when tamping about them. This method was preferred to that of using wooden casings, and gave much freedom and ease in turnings at the angles and bends in the headings.

*Grove's Battery.*—32 porous cells; 32 zinc plates; 32 platinum plates; 32 gutta-percha troughs; mahogany case for box, quicksilver, and poles; 2½ gallons nitric acid to fill the cells; ½ gallon sulphuric acid.

*Wires.*—8 copper wires from the battery to the charges, including calico lapping and tar-bands:—8 × 500 ft. = 4000 ft., and 800 ft. of wire weighing 28 lbs., 4000 ft. = 140 lbs.

The time occupied in driving the galleries, shafts, and so on, was about 9 months, the rate of progress averaging 1 foot the day of 24 hours, and 8 miners working. Powder used in blasting (3 lbs. a foot), 210 × 3 = 630; 1 in. of fuze a foot = 210 ft.; 6 lbs. of candles a week, 36 × 6 = 216; 30 bags or tarred cases.

Thus it would appear that 40,000 tons of stone were procured at an expense of 669*l.* 10*s.* 6*d.*, or about 4*d.* per ton.

At a point 150 yards in front of the cliff, the report was not loud, it resembled the sound of very distant thunder.

*Application of the Galvanic Battery to Military Purposes. Taken from H. Ward's paper, 'Profes-*

*sional Papers, R.E.,'* 1855.—The inquiry, whether the explosion of charges of powder by voltaic agency could be made generally applicable to engineering purposes in the field, seems naturally to divide itself into the following heads:—An inquiry

1st. Into the motive power.

2nd. Into the conducting medium, or the means by which that power could be conveyed to a distance.

3rd. The construction of bursting charges to produce the desired explosion.

4th. How the power obtainable could be best applied to the explosion of a number of mines simultaneously.

*Motive Power.*—The inquiry into the motive power arranges itself under the following subdivisions:—

1st. The determination of the principle by which voltaic action could, on the whole, be most effectually produced; that is, the determination of that combination of metals and acids which, while it comprises such as are generally procurable at a moderate expense and are safe to handle, would exhibit the greatest power.

2nd. The most *economical* arrangement of these, as to size and numbers; so that the power required should be produced out of the smallest bulk, and at the least cost.

3rd. The general *simplification* of the arrangement of cells and plates, so as to admit of their easy repair or replacement; the arrangement to combine portability and facility in charging and dismantling; the whole to admit of being readily packed and put together; to be durable, having as few parts as possible liable to deterioration by keep or use, and those such as to admit of many spare ones being carried with the apparatus, and easily procurable anywhere.

4th. To reduce the manipulation to a mere mechanical process, requiring in the application no chemical or scientific knowledge to work it effectually.

*Conducting Medium.*—The inquiry respecting the conducting medium naturally embraces the best metal for the purpose and the most desirable thickness under every circumstance; a ready mode of ascertaining the conducting power of any description that might be procured on the spot in an emergency; the degree of isolation required to preserve the strength of the circulating current, the best covering to effect this perfectly, and the cost of the most approved.

*Bursting Charges.*—The most approved bursting charge to be ascertained; whether that formerly made with a thin platinum or iron wire, or that discovered by Brunton, where an inflammable compound is obtained seemingly by a combination of copper, sulphur, carbon, and gutta-percha.

In the former, the best length and thickness of platinum or iron wire, and the most desirable construction for bursting charges under such circumstances; in the latter, the most approved compound, and the readiest method of making it.

*Simultaneous Firing.*—How far the power obtainable by voltaic agency can be applied to the explosion of a number of charges simultaneously by each description of bursting charge, and the best arrangements for this purpose; the rules deduced from scientific inquiry that should be the guide in considering such arrangements, and how far they must be modified in practice.

As the whole of the investigation is based on the theory of voltaic circuits, propounded by Professor Ohm, of Nuremberg, of which a translation is to be found in Taylor's 'Scientific Memoirs,' June, 1840, we cannot expect to be generally intelligible, unless we preface the experimental results with a notice of the principles established by him, and the conclusions deducible therefrom.

In considering a voltaic arrangement of one pair, say zinc, platinum, and dilute sulphuric acid with the circuit closed, Ohm has shown that the force of the current in circulation is directly as the sum of the electro-motive forces, and inversely as the sum of the resistance to its circulation.

By the sum of the *electro-motive forces* is meant the excess of affinity of the zinc for one of the elements of the solution, as, for example, the oxygen of the water in the above case, over all other counteracting agencies: this force therefore being *entirely independent of the size of the plate*, and subject solely to the nature of the metals and liquids in voltaic combination.

By the term excess of affinity it is understood that if zinc is put in sulphuric acid and water, the zinc decomposing the latter, the cause of the decomposition must be that the affinity of the zinc for oxygen is in excess of that of the hydrogen for the oxygen, with which it is in the first place combined. It is this excess that in this particular case is called the sum. In many combinations of metals and liquids, as in a Daniell or Grove, this excess is the result of more complicated forces, but in all cases the sum of the electro-motive forces is intended to express this excess.

By *resistance* is intended the obstacle opposed to the passage of the electric current by the substances through which it has to pass. It is the inverse of what is termed conducting power. We are in the habit of talking of conducting instead of resisting power, but it will be acknowledged an equally accurate conception, to view all conducting media in the light of resistances opposed to the passage of electricity, as to consider them conductors aiding its circulation. No substances in nature are perfect conductors, consequently some electric excitement is lost in each step of the transmission from particle to particle; and it seems as rational therefore to ascribe the loss experienced to a resisting agency, as to attribute the quantity obtained to a favouring one.

Let F then represent the force of the current in circulation, which it must be remembered, from what has been before stated in the first part of this paper, is equal in all parts of the circuit. Let E = the sum of the electro-motive forces, and R = the sum of the resistances. Then

$$F = \frac{E}{R}. \qquad [1]$$

The resistance R in an ordinary voltaic pair is made up of two principal and some inconsiderable portions. The former include the resistance of the wire completing the circuit, and that of the liquid intervening between the plates.

The resistance of the conducting wire which we call $w$, varies directly as its length ($l$), and its specific resistance ($s$); and inversely as the area of its section ($a$). Or,

$$w = \frac{s\,l}{a}. \qquad [2]$$

The resistance of the intervening liquid, which we will call L, varies directly as its specific resistance (S), and the thickness of the stratum (T); and inversely as the surface of the plate in contact with it (A). Or,

$$\mathrm{L} = \frac{\mathrm{S\,T}}{\mathrm{A}}. \qquad [3]$$

By specific resistance is meant the resistance due to the nature of the liquid employed, and the term is used in the same sense as we speak of specific gravity.

In fact, Ohm assumes that every atom, whether of liquid or wire, is capable of receiving excitement from the one before is in the circuit, and parting with it to the next in succession; that a loss occurs in the transmission depending on the differences of the electric forces existing in the two adjacent atoms; just as in the theory of heat the transmission of caloric between two particles is regarded as proportional to the difference of their temperatures. From this the laws in equations [2] and [3] seem obviously deducible.

There are other resistances in an ordinary voltaic circuit, namely, that of the plates themselves, and of the metallic connections between each pair, when a number are combined in series; but the great sectional area and short length of them make their absolute resistance, when compared with the rest of the circuit insignificant. They do not require a separate consideration.

The resistance R then consists of L and $w$, or

$$\mathrm{F} = \frac{\mathrm{E}}{\mathrm{R}} = \frac{\mathrm{E}}{\mathrm{L} + w}. \qquad [4]$$

Now, instead of completing the circuit by a wire, let the *plates* of a pair be connected by a medium whose resistance is insignificant, and equation [4] becomes

$$\mathrm{F} = \frac{\mathrm{E}}{\mathrm{L}}, \qquad [5]$$

representing the free circulation in a voltaic pair, when $w =$

If $n$ such pairs are arranged in series, the first zinc and the last platinum being brought in contact by a substance whose resistance is insignificant, we shall then have $n$ electro-motive forces, but also $n$ resistances; so the value of F will remain unchanged, for

$$\mathrm{F} = \frac{n\,\mathrm{E}}{n\,\mathrm{L}} = \frac{\mathrm{E}}{\mathrm{L}}; \qquad [6]$$

but there can now be added $n$ times as much resistance of wire as could be borne in equation [4], without diminishing the value of the force F below that which it represented there, for

$$\mathrm{F} = \frac{\mathrm{E}}{\mathrm{L} + w} = \frac{n\,\mathrm{E}}{n\,\mathrm{L} + n\,w}.$$

When the galvanic circuit is divided and circulates at the same time through two or more branches, the force of the current through each will be in the inverse ratio of its resistance; thus, if $r$ and $r'$ be the resistances of the two portions or branches of a conducting medium through which the current passes, $\frac{1}{r}$ and $\frac{1}{r'}$ will be the proportional force of the current in each, and their sum $\frac{r + r'}{r'}$ will be that of the current passing through both; therefore $\frac{r\,r'}{r + r'}$ will represent the resistance of a medium that could be substituted for both, and not diminish the amount of circulating force.

It is very important to bear in mind the law relative to divided currents, as it particularly concerns arrangements for simultaneous firing. We are too ready to assume that electricity selects for itself the readiest path, utterly rejecting inferior means of conduction but with respect to the circulation of voltaic currents, this idea is decidedly erroneous, and the converse is capable of easy practical demonstration.

These are the points of Ohm's theory that most immediately concern us; let us now see what conclusions are deducible from it.

Referring to equation [1], $\mathrm{F} = \frac{\mathrm{E}}{\mathrm{R}}$, it is evident that in a voltaic arrangement, the nature of whose metals and liquids has been decided on, the force F is entirely dependent on the magnitude of R, or the resistance offered to the circulation of the current as when R decreases, F increases, and when $\mathrm{R} = o$, $\mathrm{F} = \infty$, which implies that whatever arrangement of plates and acids may be made, if the resistance can be reduced to $o$, the power obtainable is infinite. That this is true may be explained in this way. It will be remembered that it was shown (see BATTERY) to be essential to the flow of a continuous current, in an arrangement, for example, of zinc, copper, and dilute sulphuric acid, that the zinc should be oxidized, the sulphuric acid should combine with the oxide to form a sulphate, and the salt should be removed by dissolution in water, leaving all things *in statu quo* for a new set of actions. Now, though these are described as subsequent operations, where no restraint is offered, they all take place at the same instant.

Now when $\mathrm{R} = o$, the initial force F is dependent on the value of E, which represents the excess of affinity of the positive metal for one of the elements of the solution over all counteracting

agencies, and is therefore limited; but if such an arrangement were made that the limited force should be developed again and again, independent of time, the resultant power, of course, would be infinite. At first view it seems as if the combination of zinc, platinum, and dilute acid, above described, is such an arrangement; and as far as the chemical action is concerned (if we leave out of consideration the adherence of the hydrogen to the negative plate) it certainly is, but there is one great check to the development, which can be diminished, but not got rid of altogether, namely, the resistance of the liquid to the passage of electricity from plate to plate. As there must necessarily be some liquid to produce excitement, so must there be a resistance R; let this but assume a value, and F becomes limited.

The development of an unlimited force F would seem, then, to be prevented by the resistance offered to the circulation of the current. It may be considered that the zinc, for instance, on being continually attacked, and finding a difficulty in getting rid of its excitement, becomes so charged that it resists a further disengagement of electricity, or, which is equivalent, resists further destruction, that is, loses its affinity for oxygen, till it can be restored to a certain state of quiescence. We have a case analogous to this in electricity produced by friction in an electrical machine, where, in order to obtain an unlimited supply of positive excitement from the glass cylinder, to charge Leyden jars, or for other purposes, it is necessary to connect the negative prime conductor with the ground, to carry off a portion of the high negative excitement produced in it by the friction it being well known that if this was not so connected it would become so highly charged as to resist further disengagement of excitement. I have here given, says Ward, this theoretical view of the varying value of F, to bring before the mind the fact that the force of the current circulating is controlled only by the value of R, and that I conceive it to be true that, *without any limitation*, so long as R is decreased F will increase.

The value of R is, as has been stated, composed of two parts, namely, the resistance of the exciting liquid and of the metallic wire closing the circuit; and how these can be diminished in a simple voltaic pair we shall find by referring to equations [2] and [3].

From equation [3] we can diminish the resistance of the liquid stratum, by bringing the plates nearer together, by substituting an exciting solution whose specific resistance is less, or by increasing the size of the plates in each cell.

From equation [2] the resistance of the conducting wire in a simple voltaic pair can be diminished, by substituting a metal whose specific resistance is less, by shortening the length of the wire, or by increasing the area of its section.

Diminishing the distance between the plates in each cell by one-half or one-third will permit us to diminish the size of each plate, *and therefore their weight*, by one-half or one-third, without a loss of power.

Increasing the section of the conducting wire, or, which is the same thing, increasing its weight per yard, will permit its length to be similarly increased, without diminishing the value of F.

In the equation $F = \frac{E}{L + w}$, taken as representing the condition of a circulating force F in a determined combination of metal and acid, we have seen that F can only be increased by the diminution of L or $w$, or both.

We have just seen the means by which L can be diminished, and supposing that by one of these it has been reduced to $\frac{1}{n}$ its value, the equation of the voltaic pair becomes

$$= \frac{E}{\frac{L}{n} + w} = \frac{n E}{L + n w}.$$

With respect to $w$, every mode of diminishing its value, which has been before mentioned, is adopted in practice; that is, a metal (copper) is employed, the specific resistance of which is the smallest known; such a size of wire is used as can with a due regard to economy be employed, and no longer length than is actually required would, of course, ever be placed in the circuit. But there is yet another mode of reducing the resistance.

For instance, if it is desired to reduce $w$ to $\frac{1}{n}$ th its present value, it is readily done by combining $n$ voltaic pairs in series, and applying them to circulate the current through $w$: the equation then stands,

$$F'' = \frac{n E}{n L + w} = \frac{E}{L + \frac{w}{n}}.$$

There are here, then, two modes of increasing the force F, and the question is, which is the greater, F′ or F″, that

$$\frac{E}{\frac{L}{n} + w} \text{ or } \frac{E}{L + \frac{w}{n}}$$

Their comparative values evidently depend on the respective values of L and $w$; for if L is greater than $w$, F′ is greater than F″; if equal, equal; and if less, less. From this we have the following rule:—

When the resistance of the liquid stratum is greater than that of the wire, it is more advantageous to increase the size of the plates of a voltaic pair than to arrange a number in series. When the two resistances are equal, it matters not which is done; and if the resistance of the wire is greater than that of the liquid, the development of the force F is most economically obtained by placing several pairs in series.

This is a most important principle to bear in mind (as will be hereafter shown) when making an arrangement for the explosion of a series of charges; for by a simple alteration of the disposition of cells, effects can be produced which without the knowledge of this principle would be unaccountable.

The rule above made evident is supported by practice. In electro-plating, where the metallic portion of the circuit is short and ample in size, experience has taught that it is more profitable to increase the size of the pair in action. But in the explosion of charges of powder at long distances, where the metallic resistance is usually extensive, it is found more economical to arrange plates in series.

The explanation usually given for the necessity of different arrangements for the two purposes is, that in electro-plating a quantity of electricity is required, while in exploding charges intensity is essential. Intensity of heat (for this is one of the forms in which electricity can be made apparent) is a property partly dependent on the quantity of heat, and partly on the space it occupies. An increase of intensity can be obtained by putting the same quantity into less space. The same *quantity* of caloric applied to a 12 and 24 lb. shot would produce heat of various degrees of intensity. Intensity, therefore, is directly and entirely dependent on the space into which a given quantity of heat is compressed, not upon an arrangement of cells in series. It would be equally correct to say that increasing the size of a voltaic pair would increase the intensity, as to ascribe that power to the accumulation of cells in series. In fact, both these arrangements have that power, as we can imagine the same force F being made to circulate by each mode in the same combination of metals and acid—though in one case by an arrangement in series, and in the other by having one large voltaic pair—and through two wire circuits identical in their size, length, and conductibility. In the former, assuming $n$ cells to be placed in series, $F = \frac{n\,E}{n\,L + w}$; and in the latter, $w$ and E being of the same value as above, $F = \frac{E}{L' + w}$. And for both these values to be equal it is only necessary that L' should equal $L - \frac{n-1}{n}\,w$, which value is obtainable by a proportional increase of one pair of plates, as long as $\frac{n-1}{n}\,w$ is less than L. The same force F, then, whether caused to circulate by the conditions expressed by $\frac{E}{L' + w}$ or $\frac{n\,E}{n\,L + w}$, will exhibit the same intensity on similar parts of two identical wire circuits, and the property of producing intensity is thus shown not to be confined especially to either arrangement.

To produce any required intensity it is necessary to get the requisite quantity into the given space, and this can only be done by overcoming the obstacles to its transmission. There are two descriptions of resistance to overcome, namely, that of the connecting wire and that of the liquid, and it depends on their comparative power which it is most desirable to diminish; the former can be lessened most readily by accumulating cells in series, and the latter by increasing the size of the plates.

It is practically true that in the explosion of charges at long distances the required intensity can only be obtained by accumulating cells in series; but the reason of this is evident, namely, that in equation $F = \frac{E}{L' + w}$, even if the resistance L by the increase of the size of the plate be reduced to an insignificant value, that of $w$ may still be too great to admit of the required quantity circulating through all parts, and then plates in series are essential to reduce the value of $w$, as by that means only can F now be increased.

The converse, however, is equally true, and deserves consideration. Imagine a combination of $n$ cells arranged to overcome a resistance $w$, and that the number is so great that the opposition of $w$ has been practically reduced to nothing, or the equation representing the value F standing thus—

$$F = \frac{n\,E}{n\,L + w} = \frac{E}{L + \frac{w}{n}},$$

in which $\frac{w}{n}$ is so insignificant as to admit of its being left out of the consideration, then practically $F = \frac{E}{L}$. Now, if L is so great that its resistance alone will not permit of a sufficient quantity of force circulating, then if 1000 or 10,000 cells were placed in series, we could not sensibly increase the value of F, for it could only approach, but never could equal $\frac{E}{L}$; to obtain sufficient intensity in this case it would then be essential to increase the size of each plate in the series, for by that means only could F now be augmented. These considerations are important, for they show clearly that there is a limit in each case, beyond which we can get no appreciable increase of power: in the one no further increase of the size of the plates will increase the force, unless we at the same time increase the number; in the other we may diminish the size so much as to render a large number placed in series of no value.

Returning again to equation $F = \frac{n\,E}{n\,L + w}$. It has been shown that, whatever the value of $n$, F *cannot equal* $\frac{E}{L}$, that is, *the electro-motive force of one pair restrained by the resistance of the inter-*

*vening liquid;* at the same time the combination $\frac{n\,E}{n\,L}$ has the power of circulating the force F through $n$ times the metallic circuit which $\frac{E}{L}$ could, for $F = \frac{E}{L+w} = \frac{n\,E}{n\,L+n\,w}$. These two theoretical conclusions admit of the popular explanation, that in a series of cells, with plates, say of zinc and copper, each copper, while receiving excitement from the zinc of its own cell, restores to equilibrium the zinc in the next, or that to which it is metallically connected; that is, the first copper in the series tranquillizes the second zinc, the second copper the third zinc, and so on; and then there remains only the first zinc and last copper, which require to be connected to permit each to return to a state of quiescence; of course, then, any connection uniting these two, however small its resistance, cannot have so great an *amount* of electric fluid traversing it as that which one voltaic pair is able to produce, or that expressed by $\frac{E}{L}$.

At the same time, as Ohm has shown that the quantity of electric fluid travelling by two paths to the same destination will proceed by each in quantities varying in the inverse ratio of their powers of resistance, let us imagine the quantity at the last copper plate in the series desirous to return to the first zinc, and that the zinc and copper is metallically connected, bearing also in mind that this zinc and copper are connected by another means, that is, by the alternation of metals and acid solutions, both conductors intervening between them, so that there are here two paths by which equilibrium can be restored; and now if we suppose, first, the metallic resistance insuperable, the whole of the electricity will return by the liquid; if we suppose the liquid resistance to be insuperable, tranquillity will be restored wholly by means of the metallic road. But in reality, as neither resistance is actually insurmountable, the fluid does return by both roads in the inverse ratio of their resisting powers. Conceive, then, one voltaic pair with the circuit closed by a wire of any given length. In this position a certain amount of electric force is proceeding from the copper to the zinc by the wire, the remainder returning by the liquid, the proportion depending on the resisting powers of each; if, then, we increase the resistance of the liquid portion $n$ times, we can proportionally increase that of the metallic portion without altering the absolute quantity proceeding by each path. In a combination of $n$ cells the former is done, and then we are enabled to do the latter. When $n$ cells are used in series, $n$ times the resistance is opposed to the return of the electric fluid at the last plate by the liquid to the first, for it has to traverse $n$ thicknesses of solution and $n$ pairs of metallic plates, and so we can add on $n$ times as much metallic wire resistance without diminishing the quantity, thereby circulating below that which would circulate through the original length, were but one voltaic pair to be employed.

This passage is not perhaps quite clear, as it would imply that an increase of the liquid resistance, taken by itself, would allow an augmentation of the wire resistance also. At page 538 the formula explains it, as it is shown that $F = \frac{E}{L+w} = \frac{n\,E}{n\,L+n\,w}$; $\frac{E}{L+w}$ representing the conditions of a single pair, and $\frac{n\,E}{n\,L+n\,w}$ that of a series of $n$ pairs, in which L having been increased $n$ times, $w$ has also been increased in the same proportion; but the numerator or electro-motive force has been likewise increased $n$ times.

Proceeding on the principles thus developed by Ohm's theory to inquire into the power of every description of battery, it will, we hope, be clear from what has been said that it was in the first place necessary to ascertain the comparative value of L and $w$ in the equation $F = \frac{E}{L+w}$ before it could be decided whether the force F would be most economically produced; and secondly, the comparative value of E to show the relative electro-motive energies of the several known combinations.

Before proceeding to detail the experimental results which determined the choice of the motive power or description of battery for military purposes, we may enumerate those that have been submitted to examination, namely:—

*Wollaston's*—Zinc and copper and dilute sulphuric acid, and its modifications of zinc and iron, and copper and iron.
*Smee's*—Zinc, platinized silver, and dilute sulphuric acid.
*Grove's*—Zinc and dilute sulphuric acid, platinum, with strong nitric acid.
*Daniell's*—Zinc and copper, with dilute sulphuric acid and sulphate of copper.
*Dalgleish's*—Zinc, platinum, and nitric acid.
*McCallan's* batteries, of which there are several varieties.

These several batteries can be classified under two heads—those in which an evolution of gas takes place on completing the circuit, and those in which, for the attainment of constancy, the gas is absorbed by a chemical process. To the former class belong Wollaston's and its modifications, Smee's, and Dalgleish's; and to the latter, Daniell's, Grove's, and McCallan's.

The advantages of the first class consist in the simplicity of the arrangements, the use of but one acid, the necessity for porous cells being thus avoided; while the second has the advantage of producing greater constancy by a chemical arrangement, though at the expense of simplicity.

Wollaston's, Smee's, Daniell's, and Grove's batteries have been for some time before the scientific world, and are well known. McCallan has organized several combinations of metals and acids which require notice. In one, cast iron is simply substituted as the negative metal for the platinum of Grove's; in other forms he uses successively platinized iron, platinized lead, chromed iron, chromed lead. He also varies the exciting solutions. Now he employs concentrated nitric and doubly-rectified sulphuric acid in contact with the iron; then, again, this solution is

modified by mixing four parts of sulphuric acid, two of nitric, and two of a saturated solution of nitre together. If, in this latter mixture, nitric acid is dispensed with, its place must be supplied by an addition of the nitric solution, which, he states, need not be saturated. He also finds that nitrate of soda could be substituted for nitrate of potash, though with a loss of power to be repaid by cheapness of material.

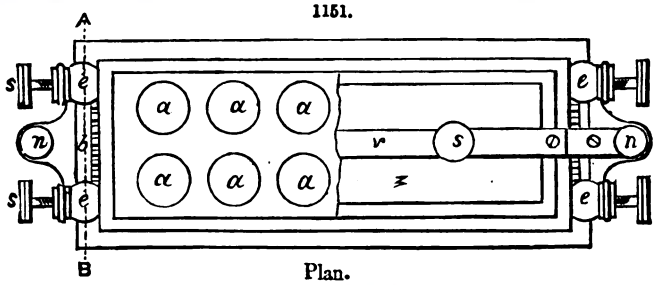
Platinized or chromed cast iron answers as well as platinized lead, and cast iron without being chromed appears to act as well as platinum.

After weighing well the relative qualities of lead and cast iron, McCallan prefers the latter, principally because it does not require platinizing.

From these remarks it seems just to infer that cast iron not platinized—that is, plain—was, on the whole, better than platinized lead, platinized iron, or chromed iron; and if this is the case in the laboratory, it will be much more so in the field, for the platinizing process will, owing to the destruction of the iron, require to be frequently repeated, entailing much expense and trouble, and requiring scientific knowledge and practice. It was only necessary then to test the merit of the substitution of cast iron for the platinum in Grove's, and the use respectively of nitric and sulphuric acid mixed, concentrated nitric and sulphuric acid mixed, and concentrated nitric acid alone, when applied to produce voltaic action. These trials have been made.

The battery made by Dalgleish, of the Ordnance Survey Office, Dublin, deserves particular notice. He employs zinc and platinum for the metals, and strong nitric acid, though it should not be concentrated, for the solution. Platinum cups containing nitric acid have suspended over them, attached to a bar, cylinders of zinc, which are kept from the influence of the acid by strong elastic bands. At the moment the voltaic action is required, a pressure on the bar immerses the zinc, and at the same time, by an ingenious arrangement, completes the connection of the several cells. An action ensues, and the desired effect being produced, the removal of the hand allows the elastic bands to withdraw the zinc cylinders, and yet to keep them suspended over their respective cups from further destruction. See Figs. 1151 to 1153.

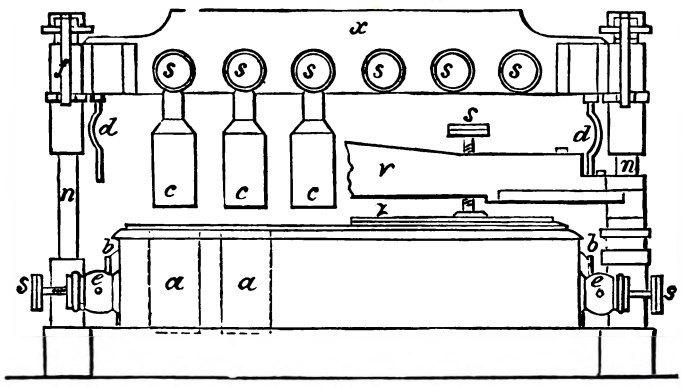
1151.




Plan.

*Reference:*—*a a*, Platinum cylinders in metallic communication with the platinum connectors *b b*. *c c*, Zinc rods in communication with the platinum connectors *d d*. When in action *d d* press lightly on *b b*, thus connecting each zinc rod with its corresponding platinum cylinder.

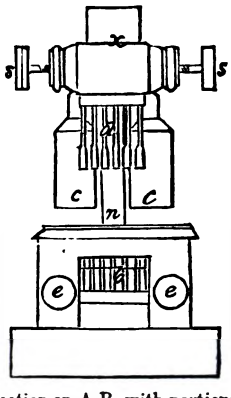
1152.




Elevation.

*Reference:*—The right-hand zinc rods are omitted to show more clearly the mode of closing the cylinders with the lid *z*, when not in use. *f f*, Straps of india-rubber, which are intended to raise the bar *x* when pressure is removed, so as to stop the action.

1153.




Section on A B, with portions of the battery in elevation.

*Reference:*—*e e*, Poles of the battery *s s*, Screws. *n n*, Pillars on which the bar *x* slides.

Though this battery is classed with those in which an evolution of gas occurs they can by no means compare with it in energy. Its electro-motive force is very great; nor can we by description do justice to the ingenuity of the arrangement by which the zinc cylinders are kept out of the acid till their destruction is necessary; at the proper moment the pressure of the hand immerses them, and simultaneously makes the connection of the several cells.

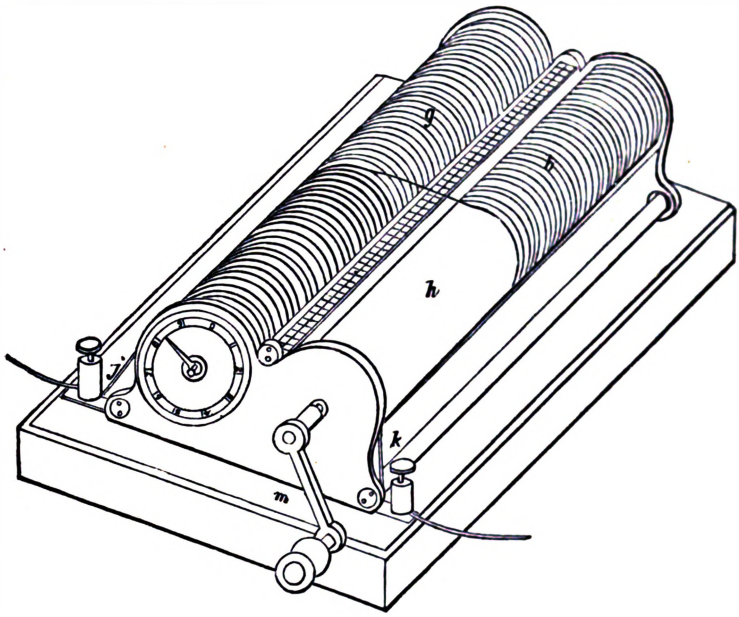
With respect to Wollaston's battery of zinc and copper, and the modifications of it before mentioned, we did not submit them to any detailed examination, for we believe it is well known and generally acknowledged that Smee's principle is superior to them in *every* way. Having satisfied himself of the truth of this general opinion, Ward tested more carefully the power of a Smee, and the result will show how inadequate such an arrangement is for the intense and constant heat required for explosions of powder.

The plan pursued in the inquiry into the merits, or productive values, of these several forms of battery, was to ascertain first the most advantageous size and arrangement of plates to cause the circulation of the required amount of force in each, and then to select the one best for use in the field.

The principle on which Ward proceeded to obtain these values was by introducing variable resistances into the circuit, and bringing the force of the current circulating in each case to an equality; then, by equating the two expressions obtained, we can arrive at the electro-motive force or resistance of the liquid, according to the conditions of the experiment.

To apply the principles mentioned, it is necessary to have the means of varying the interposed resistance gradually between any required limits; and the instrument employed was a Rheostat. **Fig. 1154.**

1154.




The following is a description of it:—*g* is a cylinder of wood with brass termination, and *h* a cylinder of brass, both of the same diameter, and having their axes parallel to each other. On the wood cylinder a spiral groove is cut, and at one of its extremities is attached one end of a long copper wire of small diameter, which, when coiled round the wood cylinder, fills the entire groove, and is fixed at its other end to the extremity of the brass cylinder. The two springs *j* and *k*, pressing one against the brass terminal of the wood cylinder, and the other against the brass cylinder *h*, are connected with two binding screws for the purpose of receiving the wires of the circuit. The movable handle *m* is for turning the cylinders on their axes; when it is attached to the cylinder *h*, and is turned to the right, the wire is uncoiled from the wood cylinder, and coiled on the brass cylinder; but when it is applied to the cylinder *g*, and turned to the left, the reverse is effected. The coils on the wood cylinder being insulated and kept separate from each other by the groove, the current passes through the entire length of wire coiled on that cylinder; but the coils on the brass cylinder not being insulated, the current passes immediately from the point of the wire which is in contact with the cylinder to the spring *k*. The effective part of the length of the wire is therefore the variable portion which is on the wood cylinder.

A scale is fixed to measure the number of coils unwound, and the fractions of a coil are determined by an index which is fixed to the axis of one of the cylinders, and points to the divisions of a graduated scale.

The instrument employed was made on the same principle, though of larger dimensions, as more suitable to the inquiry in view. The cylinders were 10 in. long, and exactly 10 in. in circumference, the wire employed being about ·045 in. diameter, and weighing about 53 grains a yard. The wood cylinder when covered held 190 turns of such wire, or 52½ yds.; and it was assumed as the standard measure of resistance, estimating and expressing all other resistances in terms of this wire.

Some mode was requisite by which the force of the current circulating could be measured. A delicate astatic galvanometer first occurred to Ward as suitable for the purpose; but he found that, though well adapted for the measurement of feeble currents in circulation, it was not so suitable for measuring those of such great energy as are required for the purpose of exploding

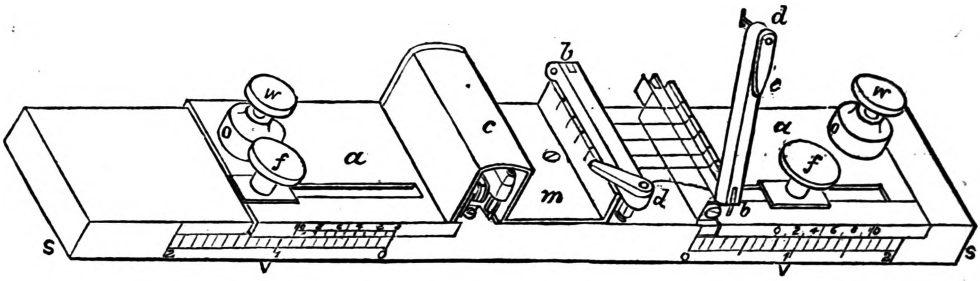
powder. It seemed that the resistance of the liquid stratum and the electro-motive forces were, in some forms of battery, dependent in a degree on the amount of electric current in circulation, or when the quantity was so minute as to be accurately measured by a galvanometer the value of L was less than when a more energetic current was passing. On the other hand, when a sufficiently strong current was circulating, the deflection of the galvanometer needle was so great, that small variations in the extent of the circuit produced no effect on the variation of the needle. Frequent changes were also apparent in the magnetic intensity of the needle when acted on by strong currents, so that two equal degrees of variation could not be taken as indications of the same amount of circulating force. It was therefore no easy matter to ascertain when a current sufficiently energetic for the object of the inquiry was in circulation.

With an intention, then, of ascertaining the amount of resistance and electro-motive force in every form of battery, when a current of sufficient energy for exploding powder was circulating, and at the same time to have a certain indication that such was the condition under which he was making the experiment, Ward adopted the following plan. In some part of the metallic circuit he placed a thin platinum wire, $\frac{3}{8}$th of an inch long, weighing 1·65 grain a yard. Gradually varying the metallic resistance, he then ascertained the amount at which the small wire would just melt. As the same degree of heat would always be necessary to fuse the same length and thickness of platinum wire, and as that could only be obtained by the same force of current passing uniformly through all parts of the circuit, and, moreover, as the fusion of this wire would readily ignite surrounding powder, he thus obtained a galvanometer which, at one view, gave all the information required.

It was an easy matter to design an instrument for holding the wire, or any number of wires, if required. Ward had one constructed, which also permitted of two wires being placed in successive parts of the circuit, or, if necessary, of two sets of six, the wires of each set being arranged side by side. (The reason for both these arrangements will afterwards appear.) They were held firmly between parallel brass plates; and by means of screws, clamps, and a graduated scale with a vernier attached, any length, from the smallest imaginable to 1½ in., could be introduced in the circuits for the purpose of experiment. As it is an instrument for measuring energetic currents, it may be called an intensity galvanometer.

Fig. 1155 represents this instrument. *s s* is a wooden stand, resembling a flat ruler, having two graduated scales *v v* of inches and tenths of inches corresponding to the verniers on the bent down edges of the brass slides *a a*. In the figure the right slide is represented as drawn back, and it will be observed that it carries with it a vertical brass transverse plate, provided with slits for the reception of the platinum wires, which are then kept firm by the capping bar *b d*, here represented open, but which turns on a hinge at *b*, and is secured firmly to the plate when down by the lever-catch represented at *e d*. The other ends of the wires are received in slits of a similar upright piece, which forms part of the centre plate *m*, which is attached permanently by screws to the wooden stand. This upright piece has also a lid *p d*, which is here represented as

1155.




closed on the wires. The left slide *a* consists of the same parts, but is here shown as closed in to the central upright piece on that side; the two uprights being covered by the cap C, which keeps up a metallic connection between the left and right slides, just as the platinum wires do on the other side. By removing the cap C the left slide becomes movable to the left, and wires can be inserted between the upright of the slide and that of the central plate, just as is exhibited in respect to the right-hand slide. *f f* are clamping screws to secure the slides in any required position. *w w* are screws for receiving the connecting wires of the battery. When it is only intended to use a single wire or a set of wires, from two to six, arranged side by side, the cap C must be down on one side, either the right or the left, as here represented; but when it is wished to use two distinct wires successively in line, or two sets of wires in succession, the cap C must be removed. The instrument may be made to complete the circuit, if necessary, without the platinum wires, by closing up the slide on the right as on the left side, and covering the uprights by another cap similar to C.

As before stated, there were barely 53 yds. of standard wire on the rheostat, but it was generally necessary to introduce much greater resistance than this. The means of doing so were easily obtainable, for having on hand about two miles of thin copper wire, varying from 160 to 250 grains a yard, covered with gutta-percha, in lengths varying from 75 yds. to half-a-mile, it was only necessary to ascertain the resisting power of these in terms of the standard wire, and by Wheatstone's instrument this was readily done. Thus with a piece 75 yds. long, taking a Grove's battery (though any constant battery would do equally well), Ward found that three of its cells were capable of fusing the thin platinum wire before men-

tioned, when 119½ turns of the standard wire coiled on the wood cylinder of the rheostat wire were included in the circuit; and the same three cells fused the same length of wire when a coil of wire of *another description* 75 yds. long, together with 68½ turns of rheostat wire, composed the circuit. Now, three cells acting in series are expressed by $\frac{3\,E}{3\,L}$, that is, three electro-motive forces divided by three liquid resistances, if L represent the resistance of the liquid of one cell. The other resistances are in the first experiment composed of 119½ turns of standard wire, and the platinum wire, the amount of whose resistance we may call $p$: in the second, of 75 yds. of coil, 68½ turns of standard wire, and the platinum wire $p$. Under each condition of experiment the same amount of force was capable of circulating; calling this F, we have

$$F = \frac{3\,E}{3\,L + 119\frac{1}{2} + p} = \frac{3\,E}{3\,L + 68\frac{1}{2} + 75\text{ yds.} + p}.$$

By which we obtain 75 yds. = 51 turns; or the resistance opposed by the 75 yds. of coil was equivalent to that of 51 turns of standard wire, and whenever this portion was introduced into the circuit it was considered equivalent to 51 turns of standard wire. Again, with a piece of greater length, eighteen cells of another battery were capable of fusing the platinum wire, the current passing through an equivalent of 868⅜ turns of standard measure, and when a piece 550 yds. long was introduced, the same result could be produced through but 88⅛ turns. The 550 yds. piece was then = 868⅜ − 88⅛ = 780¼ turns of standard wire: and to show the degree of accuracy attainable, each result (namely, 868⅜ and 88⅛) is the mean of eight observations; the first eight observations differing from the mean 868⅜ as follows—

$$\tfrac{1}{4},\ 2\tfrac{3}{4},\ 2\tfrac{1}{4},\ 1\tfrac{3}{4},\ 2\tfrac{1}{4},\ \tfrac{3}{4},\ 3\tfrac{3}{4},\ 4\tfrac{1}{4};$$

and the second eight from the mean 88⅛ as under—

$$5\tfrac{1}{8},\ 6\tfrac{7}{8},\ 2\tfrac{7}{8},\ 2\tfrac{7}{8},\ \tfrac{1}{8},\ 4\tfrac{1}{8},\ 2\tfrac{1}{8},\ 1\tfrac{1}{8}.$$

The probable error of the mean difference resulting from these sixteen observations does not exceed 1·15 turn; that of a single pair of observations being within 3·3 turns. The galvanometer is, however, capable of measuring to a still greater degree of accuracy, if necessary. The above observations were made with a battery not particularly suitable to the purpose, and with less than the usual degree of care, in a period of less than a quarter of an hour; the coil in question not being required for the subsequent experimental inquiry. The instrument admits of a repetition of from 40 to 60 observations an hour with ease, and thus, in a short time, it would be easy to obtain a result free from any but an almost inappreciable error. In a similar manner the resistance of any length of wire could be reduced to a standard measure; and as the wires were covered with gutta-percha, Ward was able to arrange them in coils round the table on which the battery stood, introducing such as were required by the nature of the experiment.

As the thin platinum wire before mentioned necessarily formed part of the circuit in *every experiment*, it was requisite to ascertain its resistance in terms of standard measure. This was done by first introducing one, and then two such wires, all of the same length, in different portions of the circuit (for which, as has been described, the galvanometer was adopted), and producing a fusion in each case *by the same power of battery*. The amount of standard resistance or length of standard wire which had to be taken out in the second case to produce fusion, was equivalent to the resistance of one platinum wire. This was found, by the mean of six pairs of observations, to be 60⅜ turns. The probable error of this result being ·1 turn, and that of one pair of observations = 2·3 turns, is equivalent—as the wire is but ·375 in. long—to ·00618 in. in the former case, and to ·0142 in the latter.

A ready mode of checking the correctness of this result is always at hand: it is as follows:—Find the utmost length in standard measure of the metallic circuit (not including that of the platinum wire) which will admit of any even number of cells in series, say twelve, fusing that wire. Ascertain the same with each half, or six of those cells. The sum of the circuits of the two sixes deducted from that of the twelve will give the standard resistance of platinum wire. This will be a true result, subject of course to corrections for errors of observation, however irregularly the cells may be working *inter se*; and a reference to the formula will easily explain the rule.

It might be supposed that the resistance of these several wires would be ascertainable by the formula $w = \frac{s\,l}{a}$, when the specific resistance, the length, and the area of the section are known; or if they are all of copper, the specific resistance being the same, that the length divided by the weight a yard should give the comparative resistance; but an approximate value can only be obtained by such measures. A small variation in the description of copper from which the wire is manufactured would affect the value of $s$, and the difficulty of obtaining in wires of small diameter a correct value for $a$, or, what is its equivalent, the difficulty of obtaining a long wire of a uniform weight a yard, would increase the probable error of the true result. For instance, several portions of the same wire weighed 249·5, 233·5, 228·6 grains a yard, as ascertained by a delicate balance turning to $\frac{1}{500}$ of a grain, thus denoting an irregularity due either to the manufacture or to the quality of the copper.

It is therefore fortunate that Wheatstone's rheostat furnishes such a ready, as well as practical, mode of ascertaining the degree of resistance of all descriptions of wire *without a knowledge of any of the factors of the equation* $w = \frac{s\,l}{a}$.

The amount of error into which we may be led by determining the resistance from calculation instead of by experiment may be seen from the following Table, in which that practically ascer-

tained and that calculated, each in terms of wire weighing 53 grains a yard, are placed side by side:—

| Actual length of Wire, in Yards. | Weight per Yard, in Grains. | Calculated Resistance in turns of Rheostat. | Actual Resistance by Experiment in turns of Rheostat. | Percentage of Error in Calculation. | Percentage of Probable Error in ascertained Resistances. |
|---|---|---|---|---|---|
| 75 | 233·22 | 61·3 | 51 | + 16·8 | 0·58 |
| 125 | 228·66 | 104·3 | 83¾ | + 19·7 | 0·53 |
| 245 | 233·5 | 200·2 | 172¾ | + 13·7 | 0·46 |
| 495 | 249·5 | 378·5 | 322½ | + 14·8 | 0·34 |
| 280 | 166·2 | 321·4 | 401⅝ | − 24·9 | 0·41 |

Thus the first four lengths (which, as before stated, are portions of one original piece, and were therefore probably manufactured from one description of copper) are tolerably consistent among themselves, though differing on an average by more than 15 per cent. *plus* from the standard, whereas the last piece shows a *minus* error of nearly 25 per cent., making an aggregate error between the two descriptions of copper wire shown in the Table of about 40 per cent.

Here, then, is made apparent one of the probable sources of failure in demolition by voltaic agency. The different diameters of the pieces of 495 yds. and of 280 yds., though apparent on *close* examination, would not strike a casual observer; in fact they were purchased from the Gutta-percha Company as one description of wire, yet the resistance of the *shorter* lengths as compared with the *longer* is as 402 to 323! If, then, calculating on the experimental results obtained from the former, the same length of the latter wire had been used in any proposed demolition, the probable result would have been total failure.

The last column shows the probable error in the ascertained resistance, which averages under one-half per cent. These results are more than sufficiently accurate for the purpose of the inquiry, though by no means so near as it would be easily possible to attain, since it is within the compass of an easy day's work to ascertain the resistance of all these lengths to within $\frac{1}{10}$th per cent. of probable error, and even to eliminate error altogether.

It was easy now to obtain the value of L or the resistance of the liquid stratum in any battery, as well as the proportional value of any electro-motive force. The experimental results with each battery examined now follow, being prefaced with a description of the size and mechanical arrangement of each. Ward had, for the commencement of the investigation, that battery of Grove's construction which was employed in the demolition of Seaford cliff in 1850. It was supplied to the Engineer Department at Portsmouth as the best form and description of voltaic implement known for the purpose, and therefore deserves a description to show how much such an instrument is capable of modification, when required solely for blasting purposes.

The battery consisted of ten cells, in each of which was suspended one plate of platinum, with two of zinc facing it, one on each side, at a distance of $\frac{3}{4}$ of an inch; the exciting solution being dilute sulphuric acid for the zinc in the proportion of 1 of acid to 8 of water, and strong nitric acid for the platinum, the two acids being separated by a porous earthenware diaphragm; the plates in action in each were two 9″ × 7″ of zinc, and one 6″ × 6″ of platinum; each cell requiring 2¾ pints of dilute sulphuric acid, and $\frac{3}{4}$ of a pint of nitric acid. Its weight when charged was 168 lbs., of which 40 lbs. was due to solution and 44 lbs. to zinc plates.

Each cell then had the power of circulating the standard force required, that is, a force capable of fusing thin wire, through a resistance of 66½ turns standard measure.

It was evident, on first sight of the instrument, that this battery would admit of considerable reduction, if the principles of Ohm's theory were correct; and that if the distance between zinc and platinum was reduced from $\frac{3}{4}$ to $\frac{3}{8}$ of an inch, one-half the weight of zinc (= 22 lbs.) and a corresponding bulk of acid could be dispensed with, without lessening in any degree the power of each cell. With this consideration in view, and also wishing to compare an arrangement on Grove's principle with one of Smee's batteries, Ward had one of the former constructed with twelve cells, two zinc plates 4″ × 2″ being in action in each cell, one on each side of a platinum plate 4″ × 4″ and at a distance from it of about $\frac{3}{8}$ of an inch. The experimenter also had the platinum plates platinized, the original object of which was to work this identical battery as a Smee, by dispensing with the porous cells and nitric acid; but thinking afterwards that this might appear to some as hardly a fair trial of Smee's arrangement, Ward abandoned that idea, and used these platinized platina plates in the Grove's arrangement only. It will be seen subsequently that platinized platina opposed to zinc gives a stronger arrangement than platinum only—a fact which was first noticed by McCallan.

The investigation was intended to find the power of the several voltaic combinations when excited by ordinary agents, that is, those which might readily be obtained: our author did not enter into an inquiry, except on special occasions which will be particularly noticed, as to the degree of power attainable by the use of concentrated nitric acid, doubly-rectified sulphuric acid, or such reagents as are difficult or expensive to procure, or dangerous to handle; but confined himself to the task of ascertaining the power attainable from ordinary, or what are termed commercial, acids, which do not emit fumes destructive to health.

The rule for ascertaining the merits of any voltaic combination is this. Arranging any number of cells in series, ascertain the metallic resistance that can be comprised in the circuit which will permit one platinum wire to be fused. With the same number in series, ascertain the extent of circuit which will admit of two platinum wires placed side by side in the galvanometer being fused: and these two experimental results may be obtained in five minutes at any time in the

field as well as in the laboratory, with instruments which should always accompany the battery, by a single observation of each result with a probable error not exceeding two turns; whilst by a repetition of observations, all appreciable error could, of course, be eliminated. In making these trials, it is not necessary that the operator should have any knowledge of the metals or acids of which the voltaic arrangement is constituted. The experiment will show him at once if the battery is to be trusted, and to what extent, and, if any disarrangement has occurred, how many cells to add to overcome the defect: indeed, the constancy and duration of the heat made apparent on the wire is at once an infallible and ready test of the value of the battery for explosive purposes.

The demonstration is as follows:—Taking $n$ cells in a battery whose electro-motive force is E, and resistance of liquid L, suppose a metallic resistance $w$ to be the extreme that can be interposed and yet enable a force to circulate that will cause the platinum wire to be fused; call this force F, then the equation stands $F = \frac{n\,E}{n\,L + w}$. Now, if the extreme metallic resistance, which we will call $w'$, is ascertained which admits two identical wires, placed side by side, to be fused, it is evident that the same force F must be passing along each wire at that moment, or a force of 2 F along both together; and as the same quantity of electric fluid must be passing through every part of the circuit, the equation representing the conditions under which the battery is working will be expressed by $2\,F = \frac{n\,E}{n\,L + w'}$. Now, as the numerator in both these expressions is the same, for in both experiments the same number of cells are used, the denominator in the last must be one-half of that of the first, or $n\,L + w' = \frac{1}{2}(n\,L + w)$ $\therefore L = \frac{w - 2\,w'}{n}$. Thus the average resistance of $n$ liquid strata, or $n$ L can be obtained. The use of this value of L will be better understood when we come to consider the other numerical values in each case.

Again, suppose we have two separate combinations of battery, say a Smee and a Grove arrangement, of which it is desired to determine the comparative value of the electro-motive forces: let the electro-motive force be E and E', liquid resistance L and L', and the quantity of metallic circuit that each will bear when $n$ cells are combined, and yet permit the standard force, which we will in future call a force F, to circulate, be $w$ and $w'$. Let the amounts $w$ and $w'$ require an increase or diminution $= a$ and $a'$ of metallic resistance when a force F" is required to circulate. We then have in the first case,

$$\frac{\text{Smee.}\ n\,E}{n\,L + w} = F = \frac{\text{Grove.}\ n\,E'}{n\,L' + w'}, \text{ and in the second } \frac{\text{Smee.}\ n\,E}{n\,L + w \pm a} = F' = \frac{\text{Grove.}\ n\,E'}{n\,L' + w' \pm a'};$$

then of course E : E' as the sums of the respective denominators in each case, but they are also as the differences of the denominators of their respective fractions, that is to say, as $a$ to $a'$, or $E : E' :: a : a'$.

In all these observations the forces F and F' have been in the ratio of 2 to 1, to simplify the calculation; and the equations under the conditions became

$$F = \frac{12\,E}{12\,L + w};\quad F' = 2\,F = \frac{12\,E}{12\,L + w \pm a},$$

which being reduced, for the purpose of determining L or the liquid resistance, gave $12\,L = w - 2(w \pm a)$: and on these principles Ward took the observations that follow, the number of cells in series in all cases being twelve.

With the Grove's having plates, 4" × 4", of zinc, and platinum in action in each cell,

1. The metallic resistance interposable for 12 cells, when one wire was fused .. .. .. .. .. .. .. .. .. .. .. .. } or $w = 775\frac{1}{2}$ turns.
2. With two wires .. .. .. .. .. .. .. .. .. .. .. .. or $w - a = 350\frac{1}{2}$ „

$\therefore 12\,L = 775\frac{1}{2} - 701 = 74{\cdot}5$ turns; the probable error in this value of 12 L, as calculated from the nature of the observations, is $= 1{\cdot}7$ turn; that of $775\frac{1}{2}$ turns, similarly calculated, is equal to 2 turns.

The electro-motive force of this battery as compared with any other would be the difference of these two observations in each case, that is to say, the difference of the denominators of the equations F and F', as before stated. In the present case this is $775\frac{1}{2} - 350\frac{1}{2} = 425$, having a probable error of $1{\cdot}6$.

The duration of the power of this battery, or its constancy, as it is called, is deserving of notice. The results just given show its energy about an hour after charging, at which time, the porous cells being well saturated, it may be considered to have been at its maximum. During the day it was experimented with sufficiently to fire 300 charges, and at the end of seven hours the experiments above described were repeated in the same order. No. 1 gave $753\frac{1}{2}$ turns; No. 2, $332\frac{1}{2}$, from which 12 L = 88, and comparative value of E = $420\frac{1}{2}$. Thus the resistance of the liquid had, as regards itself, increased 18 per cent., and the electro-motive force 1 per cent.; but the two together had reduced the available energy of the battery from $775\frac{1}{2}$ to $753\frac{1}{2}$, or not 3 per cent. This constancy is readily attainable by carefully amalgamating the zinc plates before charging, an operation occupying a few minutes; and it has been found on this as well as on other occasions that the battery will continue sufficiently constant for all practical purposes for a period of twelve hours. The small loss of power noticeable here is probably owing to the fact that it was always Ward's custom in charging the several batteries to mix the sulphuric acid and water immediately before filling the cells; this, as is well known, raises the temperature of the mixture above that previously sensible in either of the liquids, and as the temperature is heightened the conducting power of the

solution is increased; but this power diminishes as the solution cools, which it gradually does. On the present occasion sulphuric acid and water, each at 40° Fahrenheit, when mixed in the proportion of one measure of acid to eight of water, gave a resulting temperature of about 70°.

When this battery is in its full strength, the amount of resistance commanded by 12 cells, that is, the amount of metallic resistance which can be added to the circuit for each cell in series without diminishing the value of the circulating force below the standard necessary for fusion, is = 775⅓ turns for the 12, or 64⅝ for one cell; but it will be remembered that the power of one cell in the large Grove did not exceed 66⅓ turns, so that this small difference is the only loss a cell by reducing the battery. In respect to the gain, the quantity of nitric acid to charge each cell has been diminished from ⅜ to ⅛ of a pint, and the dilute sulphuric acid from 2⅜ to ⅛ of a pint. These two alone diminish the cost of charging 10 cells from 7*s*. 9*d*. to 2*s*.; but as this acid lasts only 12 hours, while the others are available for 24, the comparative cost should stand as 7*s*. 9*d*. to 4*s*. The weight of 10 cells of this battery when charged was only 27 lbs., while that of the large one was 168 lbs. The cost of construction was less than one-half, and the cubical contents less than ¼. So that while but 1⅛ per cent. of power a cell has been lost, the gain has been 50 per cent. in prime cost, the same in working, 600 per cent. in weight, and 700 per cent. in bulk.

Referring back, let us substitute in the equation $F = \frac{n\,E}{n\,L + w}$, the value of $n = 12$, $n\,L = 74\frac{1}{8}$, and $w = 775\frac{1}{3}$, and we have $F = \frac{12\,E}{74\frac{1}{8} + 775\frac{1}{3}} = \frac{E}{6\frac{5}{24} + 64\frac{1}{24}\frac{5}{7}} = \frac{E}{70\frac{5}{6}}$, in which $70\frac{5}{6}$ represents the utmost amount of resistance in standard measure that this principle of battery will bear a cell, without reducing the amount of circulating force below the force capable of fusing the thin wire, that is the force F, and in which $\frac{E}{5\frac{5}{24} + 64\frac{1}{24}\frac{5}{7}}$ represents how this total resistance is apportioned between the liquid and metallic circuit, in this particular sized battery. But the same resulting force could be obtained by a battery working under any of the following conditions, namely

$$F = \frac{E}{24\frac{5}{6} + 46} = \frac{E}{70\frac{5}{6}}, \qquad [1]$$

$$= \frac{E}{35\frac{5}{12} + 35\frac{5}{12}} = \frac{E}{70\frac{5}{6}} \qquad [2]$$

$$\text{or} \quad = \frac{E}{70\frac{5}{6} + 0} = \frac{E}{70\frac{5}{6}}. \qquad [3]$$

The first of these can be produced by a diminution of the size of the plates from 4″ × 4″ of surface in action in each cell to 2″ × 2″; and as this reduction of size would not diminish the power a cell 30 per cent., or from 64⅛ to 46, while it might reasonably be expected that the expense of charging, weight, bulk, and cost of battery would be diminished at least 100 per cent., this modified form is evidently preferable.

No. 2 is, theoretically speaking, the most economical form under which any principle of battery can work for the circulation of the force required, which in this case is to fuse the particular platinum wire that we have been using, that is, when the liquid resistance of each cell is equal to its available energy; and in a Grove's combination the expression represents plates about 1·66 in. square in each cell.

The third expression represents a battery working under such conditions that if 1000 cells were placed in series they would not have the power of circulating the force F through a metallic circuit of 1 ft.

Theoretically speaking, No. 2 is the most economical form of battery; but other considerations forbid its adoption. To obtain the power, $35\frac{5}{12}$ the cell indicated by the equation, each compartment must be carefully filled to the top, as failing to do this by a quarter of an inch would sensibly diminish the power a cell. Any deterioration in the strength of acid employed would have the same effect, and the whole quantity employed being so small, it would deteriorate soon after the battery was charged. It will be seen that the acids used in the Grove, of which the zinc surfaces in action were 4″ × 4″ in each cell, were available for but 12 hours, while that in the larger size was equally so for 24 hours. Reasoning from this, it could then hardly be expected that the small battery represented by equation No. 2 would remain efficient for one hour, or work economically for one quarter of an hour.

One more condition of this equation deserves notice, namely, $F = \frac{E}{0 + 70\frac{5}{6}}$. This cannot practically be attained by any construction, for the liquid resistance must be an absolute quantity; but it shows the important fact that *however large* the plates of a Grove's combination, such as the one we have been considering, are made, the force F could not circulate if in *each* cell was developed resistance equivalent to $70\frac{5}{6}$ turns, while *two* cells 2″ × 2″ can bear a resistance more than equal to this, and yet circulate the required force with ease; in other words, that for the circulation of the force we require two pairs of plates in series, each 2″ × 2″ in surface, which are more than equivalent in force to one plate even a mile square.

No. 1 arrangement having then been decided on as the best, a battery exactly similar to the former was made, but having zinc plates 2″ × 1″ overlapping platinum 2″ × 2″; the former facing the latter on each side, and thus giving a surface of each metal 2″ × 2″ in action in each compartment. This diminution in size permitted the zincs to be brought somewhat nearer; and, instead of being ⅜ of an in. from the platinum, they were $\frac{5}{16}$.

The experiments Nos. 1 and 2 were made with this battery, giving the following results as the mean of eight observations of each: No. 1 = $571\frac{19}{24}$; No. 2 = $162\frac{7}{12}$; from which the comparative

value of E = $409\frac{5}{24}$, and the resistance of 12 L = $245\frac{5}{8}$: the probable error in each result being 1·5. The diminution of the comparative value of E from 425 to $409\frac{5}{24}$ is attributable to the platinized platinum being used in the former case, while ordinary sheet platinum was employed in this, and not to a diminution of size, which does not influence E. The sum of the resistances of the liquid in twelve cells had increased from 74·5 to $245\frac{5}{8}$.

Now, remembering that the plates had been reduced to $\frac{1}{4}$ the size, but had been brought nearer in the proportion of 5 to 6, calculation from the first result would give the second

$$\frac{74\cdot5 \times 4 \times 5}{6} = 248\tfrac{1}{2},$$

whilst experiment gives $245\frac{5}{8}$. Assuming the value of 12 L = $245\frac{5}{8}$ or L = 20·47, and that of $w = \frac{571\frac{19}{24}}{12} = 47\cdot65$; the expression $F = \frac{E}{L + w}$ stands $\frac{E}{20\cdot47 + 47\cdot65} = \frac{E}{68\cdot12}$, showing that when the platinum is *not platinized* a Grove will bear a resistance of but 68 turns of standard measure instead of nearly 71, as before, to each cell.

Referring back to the largest Grove, namely, that with zinc plates 9″ × 7″ and platinum 6″ × 6″, we may consider the area of the mean section of the fluid on each side = 49½″, and the plates being $\frac{3}{4}$ of an in. apart, facing the platinum on each side, the value of 12 L in this battery by calculation would be $\frac{74\cdot5 \times 16}{49\cdot5} = 24$ nearly, or about 2 turns a cell; and as the available energy of the battery is $66\frac{1}{2}$ turns, the condition under which the largest Grove circulates a force F is numerically expressible thus; $F = \frac{E}{2 + 66\frac{1}{2}} = \frac{E}{68\frac{1}{2}}$, which, admitting experimental error, is the same expression as that obtained from plates but 2″ square; thus showing that increasing the size of plates does not increase the electro-motive energy, that is the value of E, for the superior available energy of $66\frac{1}{2}$ turns in the large Grove is merely due to the diminished resistance.

This principle has been established, both by Ohm's theory and experiments, and required no further demonstration, except to bring the consideration of it to special notice as materially affecting a part of the following inquiry.

The batteries hitherto used, it will be borne in mind, were made with zinc plates *overlapping* the platinum plate, and facing it on each side. Thus the outer surface of the zincs was not directly opposed to any negative metal. To ascertain if this portion did any work, Ward carefully covered with a thick coating of sealing-wax varnish the outer surfaces, so that it was impossible they could be acted on, and then tried on a subsequent day the variation of E for 12 cells, as compared with former experiments, but he found no diminution of power. To make sure that this was not owing to any peculiarly good acid used on that day, he removed the varnish from each plate and reinserted them in the same solutions. The battery was found somewhat diminished in power, but very slightly, not more than 2 per cent., though if the outer surfaces had been acting, it ought to have *increased* in power. This was probably owing to the longer time it had been in action. These trials evidently proved that no sensible power is obtained from the outer side of a plate, or from any other surfaces that do not directly oppose each other; for had there been 3 per cent. of increase it would certainly have made itself apparent. It is not at all surprising that it should be so; for, referring to the principles of the action, the electro-motive force, that is, the affinity of the zinc and liquid for each other, depending on their nature, and not their quantity, cannot be increased; the amount of electric fluid they can supply is unlimited, and controlled solely by the resistance of the liquid to its transmission, this resistance varying directly as the distance between the plates; and hence it seems in due course that the whole of the supply should be obtained from the parts where it can be so done with the greatest facility, namely, from those which are nearest to or directly opposing the platinum.

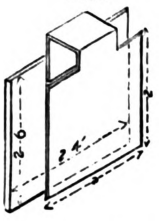
The result, however, must not be confounded with, or supposed contrary to, those obtained when the zinc, being opposed on each side by a negative metal, the battery is found to exhibit greater energy than when the copper or platinum, or whatever the negative metal may be, is on one side only; for here the zinc is directly opposed by a negative metal on both sides, and, of course, supplies electric fluid from each side, though the negative metal is, in this case, not working to the utmost advantage. The fact however made evident, to whatever cause attributable, was of great importance, as it admitted of the battery being much simplified, of dispensing with many binding-screws and of much unserviceable metal, as well as of an economy of size and weight, and an increase of power, for the plates could now be brought nearer together.

Adhering, then, to the same sized plates, a diminution of which seemed of no practical advantage, a battery was constructed with plates of zinc and platinum welded together in the simple style that zinc and copper used to be arranged in, one of each pair being in a separate cell, and the platinum immersed in nitric acid being, of course, separated from the zinc of another couple immersed in dilute sulphuric acid by the porous cell containing it and the nitric acid. A battery so made permitted the plates to be brought to an average distance of little more than $\frac{3}{10}$ of an in. from each other, and by the simple contrivance of a lid, every pair and every porous cell was kept in its place, and could be thus transmitted as ordinary baggage by rail, without extra packing or precaution. Fig. 1156 represents one of these batteries of six plates, and the connecting metallic straps are so represented as to explain the manner in which several of these batteries may be combined together; Fig. 1157 represents a single pair of plates.

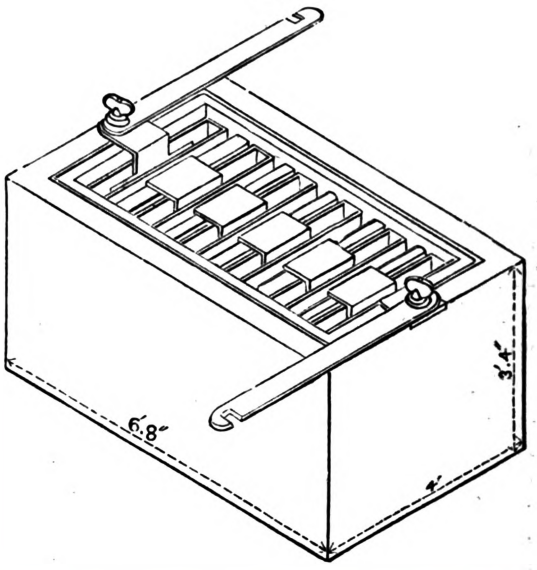
Six pairs of plates so arranged occupied a box not exceeding 7″ × 4″ × 4″, substantially made for use in the field, including binding-screws and porous cells; and the reason for this arrangement of six cells in one box will be afterwards explained. The result of the fusion of one and of two wires by twelve cells, or two box batteries of this arrangement, gave on one occasion, No. 1 = $56\frac{1}{4}$, and No. 2 = $240\frac{3}{4}$; from which 12 L = $169\frac{1}{2}$, and the proportional value of E = $410\frac{1}{4}$.

On another occasion, No. 1 gave 641, and No. 2 gave 230¾, showing that the total resistance 12 L was now = 179½, but that the value of E was unchanged; the variation in the resistance being due to the time at which the experiments were made, as the increase was probably owing to a different set of twelve having been used in each case.

1157.



1156.




If we adopt the mean of these two, or 12 L = 174·5, L = 14½ may fairly be taken to represent the resistance of the liquid when the battery is in its strongest action, namely, for the first three hours after it is charged. Also the electromotive force of a Grove battery unplatinized may be represented by the numerical value 410, as on three separate occasions experiments have given it 409$\frac{5}{6}$, 410¼, and 410¼, that of a platinized Grove being 425.

To ascertain how much the power of this battery diminished when left charged, the same experiments were repeated after six hours, and No. 1 was then found = 484½, and No. 2 = 104⅓; giving E = 380, and 12 L = 275⅓. Thus the electro-motive force had diminished 7 per cent., and the liquid resistance had increased 35 per cent. These two circumstances combining, diminished the available energy of the battery a cell from $\frac{646}{12} = 53\frac{5}{6}$ to $\frac{484\frac{1}{2}}{12} = 40\frac{3}{8}$, or about 25 per cent.

For the first two or three hours the conditions under which the force F circulates in the battery is expressed by $F = \frac{E}{14\frac{1}{2} + 54} = \frac{E}{68\frac{1}{2}}$, which expresses that each cell commands a resistance, or has an available energy sufficient to overcome a resistance, equivalent to 54 turns of standard wire. At six hours after charging, this command had decreased to 40¼ a cell, for the battery then worked under conditions expressed by $F = \frac{E}{23 + 40\frac{1}{4}} = \frac{E}{63\frac{1}{4}}$. The denominators 68½ and 64¼ denoting the comparative strength of the electro-motive force at the two periods.

This, then, is believed to be the most convenient form, size, and arrangement, for a Grove battery intended for the explosion of powder; for though on looking at the numerical value of $L + \frac{w}{n}$ it may seem that the size of the plates could yet be reduced, it must be borne in mind that, though a forces expressed by $\frac{E}{68\frac{1}{2}}$ and $\frac{E}{63\frac{1}{4}}$ are sufficient at their respective periods for fusing the platinum wire when in the galvanometer, a still greater force will be necessary for the same fusion when that wire is surrounded by powder. A small platinum wire, not exceeding ·0056 of an in. in diameter, in contact with any substance, must be subject to a great abstraction of heat but how much this is Ward was not able accurately to determine, though supposing, as he believed to be the case, that about one-third is thus withdrawn, $\frac{E}{45}$ and $\frac{E}{42}$ would more nearly represent the force required to circulate, under such circumstances, to produce fusion, giving 46 —14½, or 31½, and 42 — 23, or 19, as the available energy to each cell. Again, if a number of charges in a circuit are to be fired, a still greater amount of circulating force is desirable to ensure success, and overcome small differences in the lengths of the several platinum wires. Sometimes also a thicker platinum wire may be employed, which would require greater power to fuse. For all these reasons any further reduction is unadvisable.

Having thus decided that the size, form, and arrangement just described were the most convenient for a Grove battery, when required for the purposes of exploding powder, Ward proceeded to ascertain what increase of power he could obtain from it by using first concentrated nitric acid, specific gravity 1·500, and then a mixture of concentrated nitric and sulphuric acids, in equal proportions.

With the former, No. 1 experiment gave 701.
„ „ No. 2 „ „ 262.

From which 12 L was found = 177, and the comparative value of E = 439; and he therefore concluded that concentrated nitric acid, used in place of the commercial acid, increases the electromotive energy of the battery about 7 per cent., but has no influence on the resistance of the liquid.

The mixture of concentrated nitric acid with sulphuric acid, in equal proportions, has for its object the strengthening of the former; as the sulphuric acid, from its powerful affinity for water,

withdraws that, which is essential for the preservation of nitric acid in its liquid state. A combination of the sulphuric acid with the small quantity of water it finds disengages also a very great amount of heat, and the mixture gives forth copious fumes of nitric acid, which are destructive to health; the liquid at the same time in any but practised hands being dangerous to handle. It is desirable therefore that such a mixture should never be applied in the field, or be put into unskilful hands. Its effect in giving energy to the battery was however tried, and the result was that at first, while the acid was warm, it had the effect of reducing the resistance of the liquid, but gave no appreciable increase of electro-motive force. When the whole had fallen to the ordinary surrounding temperature, all extra power had vanished. The employment of concentrated nitric acid alone gave an increase of electro-motive energy of but 7 per cent. to each cell above that when common acid was used. The price of the former is about three times that of the latter, and its fumes are deleterious, while the latter hardly emits any. Ward therefore considers it unnecessary to employ these extraordinary reagents in any case, especially when any inferiority of power can be compensated by a proportional addition of cells.

It may be as well, before leaving the Grove principle, to show how much the original battery was susceptible of improvement for our particular object, and to do this our experimenter has arranged, side by side, the expenses of keeping each charged during 24 hours, so as to be able at any time during that period to fire one charge through conducting wires weighing about 250 grains a yard, at the distance of half a mile, assuming what his experiments have shown must be about the truth, namely, that when allowance is made for the cooling effect of the powder, a power represented by $\frac{E}{46}$ will fire instantaneously one charge, with platinum wire $\frac{3}{8}$" long, and weighing 1·66 grain a yard.

| | Large. | Small. |
|---|---|---|
| Price of acids (used to charge) .. .. | 17*s.* 6*d.* .. .. | 7*s.* 6*d.* |
| Weight of apparatus charged .. .. | 386½ lbs. .. .. | 36½ lbs. |
| Size of apparatus .. .. .. .. .. | 6 cub. ft. .. .. | ½ cub. ft. |
| Cost of „ .. .. .. .. .. | 46 guineas .. .. | under 10*l.* |

The inquiry into the power of Grove's principle of voltaic combination has been given in some detail, to show the mode of proceeding, and the conclusion to be drawn from experiment.

Bearing in mind that the size of the plates has no influence on the electro-motive force, and that any diminution of them makes itself apparent only by an increase of the resistance of the liquid reaction, it will be seen that it was easy to obtain the electro-motive energy of any particular arrangement, by simply altering the metals and exciting solutions. Thus, if cast iron was substituted for platinum, and experimental results 1 and 2 obtained, we have a complete knowledge of the electro-motive energy of one of McCallan's batteries, and also its resistance *when made of that size.* The former numerical result would stand true under any arrangement of cells and plates, and from the latter the liquid resistance of any arrangement could be deduced sufficiently near for all practical purposes.

With Daniell's battery we have but to substitute copper for platinum, and sulphuric acid and copper, in the proportions recommended by Ward, for nitric acid, and we could obtain its power under every condition, and so on with any other combination. First, with respect to Daniell's arrangement, the metals were zinc and copper; and the solutions dilute sulphuric acid, in the proportion of one of acid and eight of water for the zinc, and a saturated solution of sulphate of copper in dilute sulphuric acid, of the same strength, with the copper, the two solutions being kept apart by a porous diaphragm, whilst the temperature and conditions under which the trials were made were similar to those to which Grove's principle had been subjected

The electro-motive force as compared with Grove's was as 235 to 410, though, as these results were somewhat hastily obtained, w do not submit them as wholly accurate and the resistance of the liquid of 12 cells 2" × 2" was 242⅔ turns, Grove's having been found to have 174½ at the first hour, and 275½ at the end of six hours.

Daniell's battery has the advantage of greater constancy, its liquid resistance, while the sulphate of copper is kept saturated, remaining the same at the same temperature. On the other hand, difference of temperature has considerable influence on the success of the battery, owing in a great measure to the variation of the resistance of the liquid the dilute acid at a high temperature taking up more sulphate, which, as the mixture cools, crystallizes in the pores of the diaphragm, and thus increases the resistance and diminishes the energy of the battery.

Ward did not test what difference is due to changes of temperature, for a Daniell's arrangement being more complicated than Grove's, it was but necessary to compare them under ordinary conditions of temperature to determine their relative merits in the field, where means for raising an artificial heat cannot be generally accessible.

Grove's battery is not so influenced by changes of temperature, that indicated by 50° Fahr. being in all cases sufficient, and superior to this can always be obtained by mixing the sulphuric acid and water just previous to charging the cells.

A trial was made to form an idea what difference of power would result if a saturated solution of sulphate of copper in water was used in preference to the same in dilute sulphuric acid. The electro-motive force showed an increase of power throughout the day from 235 to 242; but the resistance of 12 cells 2" × 2" at the commencement was 605½, or nearly 2½ as much as in the former case. The latter, however, diminished during the day, owing to the more intimate mixture of the two solutions through porous cells, the battery consequently increasing in energy, and at the end of six hours it stood at 402 turns.

The solution, as recommended by Daniell gave the stronger energy, the resistance of the liquid of 12 cells being about 248, and the available energy the cell equal to about 19 turns.

The condition, then, under which a battery having surfaces of zinc and copper 2" × 2"

in action at $\frac{1}{8}$ of an in. apart, stands, is this: $F = \frac{E}{20\frac{1}{4} + 19} = \frac{E}{39\frac{1}{4}}$; and as here the value of L is greater than $w$, it is evident that such a size of plates is disadvantageous for a Daniell's arrangement.

The amount of negative metal in this battery is that comprised in a hollow cylinder of copper $3\frac{1}{2}$ in. diameter, and varying in height according to the power desired. Suspended in the centre is a zinc rod, that employed at Chatham being $\frac{3}{4}$ of an in. in diameter and 20 in. high. If, then, we take for the area of the mean section of the fluid the surface of a cylinder 20″ high and $\frac{1}{8}$″ diameter, being the mean of the diameters of the zinc and copper cylinders, we shall have a total area of nearly 134 in., at a distance of $\frac{1}{8}$ of an in.; but it has been found above that a surface of 4″ at a distance of about $\frac{1}{4}$ of an in. opposes a resistance of $20\frac{1}{4}$, and hence a surface of 134 in. at a distance of $\frac{1}{8}$ of an in. would oppose a resistance of $2\frac{1}{2}$, leaving an available energy = $39\frac{1}{4} - 2\frac{1}{2} = 36\frac{3}{4}$ the cell, when porous earthenware is employed as the intervening diaphragm.

Daniell, however, remarks that ox-gullet opposes less resistance than earthenware; and if we assume the resistance to be diminished by this substitution to $1\frac{1}{2}$ turn the cell, it will be giving the battery every advantage; and then the available energy to each cell will be $37\frac{3}{4}$ turns for firing the small platinum wire when placed in the galvanometer; or allowing, as we did before, that one-third greater force is required to fuse it when in contact with powder, the available energy a cell will be reduced to 25 turns.

Supposing, then, that the Daniell's battery, of the arrangement described by its author and the size above specified, is required to be applied to the explosion of a mine, its power the cell, as compared with the small Grove, would be about as 25 to 32, or 3 to 4 nearly. Now, the weight of 10 cylinders of Daniell's battery charged is 137 lbs., whereas 10 cells of Grove's do not weigh 8 lbs.: and further, the Daniell is much more complicated in its arrangement.

McCallan's plan of substituting cast iron for platinum was tried. The electro-motive force seemed to be about the same as in the Grove's; but as it seldom remained constant, owing to the dilution of the nitric acid and destruction of the iron, it was not easy to determine it with accuracy. It oscillated between 408 and 413, that of Grove's being 410. The resistance also of the liquid being at the commencement the same as in the Grove's, it might seem that iron, being cheaper, could be advantageously substituted for platinum; there are, however, some material objections to the substitution. The nitric acid destroys the iron during the whole period that the battery is kept charged, and the more so as the acid gets diluted, forming a solution of nitrate of iron in nitric acid, and thus is every moment deteriorating its own power of absorbing hydrogen, the battery consequently falling in energy. The nitrate of iron also impregnates the porous cells; and in dismantling the battery it is necessary to soak them for some hours in water, to be frequently changed, before permitting them to dry, otherwise the iron salt crystallizing in the cells will crack the earthenware. In addition to this, the action of the nitric acid on the iron is sometimes so great as to cause the acid to boil over, necessitating a rearrangement of cells.

All this trouble and uncertainty is dispensed with by the use of platinum, which is uninfluenced by the acid; and, though the first cost of a platinum battery is much greater, in the end it will be found both cheaper and more efficacious.

The substitution of a saturated solution of nitre and sulphuric acid in equal proportion was tried with the battery of McCallan. This also is a most troublesome arrangement; it is very inconstant, so much so, indeed, as to be quite unsuited for circulating energetic currents; it is continually boiling over, and however well it may answer for experimental researches in a laboratory, it should never be trusted for the explosion of mines. Its electro-motive energy varies according to the amount of force required to circulate; but for the quantity necessary to fuse the platinum wire it never exceeded $\frac{3}{4}$ of Grove's, and only came up to that occasionally. The object of this substitution of nitre for nitric acid is stated by McCallan to be economy; but it has been shown that Grove's battery can be kept charged at a cost of $\frac{1}{15}$ of a penny a cell an hour.

If, however, nitre could have been trusted to excite a battery, even in an inferior degree, its application would have been worthy of further inquiry, as it might sometimes happen in the field that the supply of nitric acid should fail; but so long as gunpowder remained in store there could be no difficulty in obtaining a suitable solution of nitre, by simply boiling up powder and filtering it through blotting paper. The application of this ingredient however, as we have before said, gives very precarious and uncertain results, and should never be resorted to by any but those who have had long practical acquaintance with voltaic phenomena.

We now come to another class of batteries, namely, those in which but one kind of solution is employed, the use and complication of porous cells being thus dispensed with. It was on this principle that the voltaic battery known by the name of Wollaston's battery was constructed. The defects in its mode of action, which have been explained in the first part of this paper, suggested the employment of either cast or wrought iron as a substitute for copper; the rough surface thus presented to the evolving hydrogen favouring its escape. Subsequently Smee substituted platinized silver, that is, silver on which the black powder of platinum had been previously thrown down, thus presenting an infinity of small points to aid the escape of the gas.

Probably for the circulation of currents of inferior energy, such as are suitable for electro-plating, the operation of a Smee may be perfect, and no obstruction occur by the detention of the gas: but when a force necessary for fusing platinum wire is required, the quantity of gas generated is by no means satisfactorily evolved. In fact, the battery, as it were, chokes itself by its own exertions; and if three or four successive demands are made upon it in the course of a few seconds, its power of igniting platinum wire entirely disappears,—nor does it return till the cells have been allowed to rest, and thus set free the hydrogen.

The battery from which these experimental results were obtained was identical in size and construction with the second-sized Grove before described, which was made similar to this for the purpose of ascertaining their comparative merits.

The electro-motive force of Smee's battery, ascertained when it was acting under the most favourable conditions, was, as compared with Grove's, 116 to 410, and the resistance of the liquid stratum of 12 cells = 35; that of a Grove of the same size having been found to be 74½. The available energy of 12 cells of this size = 197 turns. The equation then representing the condition under which this principle of battery circulates a force F would be represented by

$$F = \frac{E}{3 + 16\frac{1}{3}} = \frac{E}{19\frac{1}{3}},$$

that is, each cell has a command over 16⅓ turns of standard wire when a force sufficient for fusing platinum wire in the galvanometer is required; and as ⅓ greater force = $\frac{E}{13}$ is necessary for producing the same result when in contact with powder, the command would be diminished to about 10 turns a cell, a Grove of the same size commanding about 40 turns a cell; and a Grove ¼ the size about 30 turns a cell, which shows clearly at what expense (even supposing Smee's principle capable of being trusted for energetic action) we obtain simplicity of arrangement, and dispense with the use of a second acid. The size and form of the Smee with which the experiments were made are the most convenient if a Smee must be used for the explosion of powder, namely, a surface of metal = 4″ × 4″ in each cell. And yet three pairs of this are but equal to one of a Grove, whose cells are but ¼ the size.

As the Smee is superior in every way to the Wollaston and to the zinc and iron battery mentioned above, it was of no use to examine the respective merits of the two latter forms of voltaic apparatus. One form of battery, however, remains to be examined, namely, that of Dalgleish. Its principle of action has been before noticed. It consists of an arrangement of 12 platinum cups ⅞ of an in. diameter and 2″ deep, over which are suspended, attached to a bar, 12 cylinders of zinc ⅝″ in diameter. The battery is charged very readily by putting into each cup ¼ of an ounce of nitric acid. At the moment voltaic action is required, a pressure of the hand on the bar immerses each zinc in its own cup to a depth of 1⅜ in., and at the same time completes the usual connections, causing an immediate and energetic action. The withdrawal of the hand allows the zinc to be removed from destruction by the elastic bands.

The electro-motive force of this battery as compared with Grove's, using the same nitric acid in each, was as 344 to 410, and the resistance of the liquid stratum of 12 cells = 66 turns, or 5½ turns a cell. The available energy of 12 cells = 622 turns or 51⅞ a cell. The equation then representing the circulation of a force F stood $F = \frac{E}{5\frac{1}{2} + 51\frac{5}{8}} = \frac{E}{57\frac{1}{3}}$, from which it will be seen that while this battery is but little inferior to Grove's in electro-motive energy, it has an advantage over it, in that its liquid stratum opposes much less resistance in proportion to its section, this being due to the absence of Grove's diaphragms.

Also in looking at the value of L as compared with $w$, it seems as if this battery could be advantageously reduced in size. The mechanical arrangements of the battery, which are somewhat complicated, seem crowded even now into as small a space as they can well be put with safety; and any diminution of cells that could be made would sensibly increase the portability of the battery, as the zinc and platinum comprise but a small part of the actual bulk. The small resistance of liquid in each cell is partly obtained by the extreme contiguity of the zinc cylinders to the inner surface of the platinum cups, the distance being but ¼ of an in., and partly to the absence of porous cells. The successive wear and tear of the zinc will tend to increase the value of L, and diminish $w$. The advantages, then, of the Dalgleish principle are the simplicity gained by the use of only one acid, thus dispensing with the necessity for porous cells, and the extreme readiness with which it can be charged for action; it is, however, more complicated than Grove's in its mechanical arrangements, which require skilled labour of a higher degree than could generally be met with in the field to effect repairs. It is also more liable to be damaged by carelessness or accident, as it presents more assailable points.

The power of each battery, taken in conducting wire of 250 grains a yd., which, for reasons presently to be given, we have taken as the best conducting medium for general service, would enable one charge to be fired very readily at a distance of 250 yds., or in a circuit of 500; and if the requirements of a battery were limited to this, we should, where rough handling was not to be expected, prefer Dalgleish's battery to Grove's; but on service we presume far greater circuits will occasionally require to be overcome; if, for instance, a mine has to be exploded at a distance of half a mile, about 38 or 40 cells of each would be required to be placed in series, and then the arrangement of elastic bands and of the development of electric excitement by pressure of the hand becomes somewhat troublesome. The Grove is also more perfect in its chemical action, as the hydrogen set free by the decomposition of the water is immediately absorbed by the nitric acid; and the consequence is that as soon as the circuit is completed we obtain the whole power of the battery. In Dalgleish's arrangement the power visibly increases after the immersion of the zincs, probably owing in part to the heat occasioned by the intense action of the nitric acid on the zinc. This property of the battery is detrimental to firing a number of charges simultaneously in a circuit, and can only be overcome by immersing the zinc cylinders first, and then making connection with the poles. These points will present themselves with greater force to any one operating with the two batteries than they can be expected to do in any description on paper.

The actual cost of constructing the two descriptions of batteries will depend in a great measure on the price of the platinum, which is by far the heaviest item in each. Grove's battery hitherto, to save expense, has been made with platinum foil. Ward, however, prefers employing sheet platinum, of about 120 to 130 oz. to the superficial ft., for the negative. Whether foil or sheet platinum is used makes no apparent difference in the energy of the combination: but as the former is liable to tear, it would in the end be no economy to use it.

The approximate estimate of the cost of 12 cells of each description of Grove's battery, and that of Dalgleish's, is as follows:—

*Platinum-foil Battery.*—$\frac{3}{4}$ oz. of platinum foil, cells, troughs, zincs, and fittings, 3*l.* 2*s.* 8*d.*

*Sheet-platinum Battery.*—3·63 oz. platinum, cells, and so on, 7*l.* 2*s.*

*Dalgleish's Battery.*—9·96 oz. platinum, $\frac{1}{4}$ oz. pure gold, zincs, castings, and fittings, 17*l.* 10*s.*

Comparing the two Grove's, though the second is more than twice the cost of the first, it will prove more economical on service, when it is considered that 5*l.* worth nearly of material out of 7*l.* 2*s.* worth, is, with ordinary care, absolutely indestructible. Dalgleish's battery cannot cost less than 17*l.* 10*s.* for 12 cells, the arrangements requiring also more than ordinary skilled labour to complete. Assuming, then, the Grove's sheet-platinum battery to be on the whole more economical, its cost a cell, as compared with Dalgleish's, is about 1 to $2\frac{1}{4}$. The cubical space which they respectively occupy is as follows:—

12 cells of Grove's (in two box batteries) = 14″ × 4″ × 4″ = 224 inches.
„ Dalgleish's .. .. .. .. = $11\frac{1}{2}$″ × 4″ × $7\frac{1}{2}$″ = 345 „

Their comparative weights when empty are, Grove's 8 lbs., Dalgleish's $10\frac{1}{2}$ lbs.; the latter, however, would not require two-thirds of the weight of acid to be carried with it on service, and that only of one description; and though these differences may appear insignificant, they will not seem so when the quantity of available energy required in the field comes to be considered.

Assuming, as a basis of comparison, that it would be desirable to have always a power available for firing one charge at the distance of half a mile, through the conducting medium and with the bursting charge which has been selected; and also that the same number of spare cells should be kept at hand to replace those fractured or undergoing repair; the following statements will show the approximate cost, weight, bulk, and other particulars in each case:—

| | Grove's. | Dalgleish's. |
|---|---|---|
| Cost of construction of batteries .. | 51*l.* .. .. | 110*l.* |
| Weight of batteries .. .. .. .. | 54 lbs. .. .. | 70 lbs. |
| Bulk of „ .. .. .. .. | 1400 cub. in. .. .. | 2300 cub. in. |

We call attention to the extreme ingenuity displayed in the arrangements adopted by Dalgleish, to carry out his principle for producing voltaic action, as, for example, in the ready method of withdrawing the zinc cylinders from the attack of a most destructive acid, and in the plan of making the connection of the several cells, which is most original, and cannot be done justice to by any description. He combines metals and acids, so as to produce a high degree of voltaic energy by a mode that may be considered perfect; and though, on the whole, his battery, as submitted, is not so perfect in its voltaic action as Grove's, is more sensible to rough usage, and for these as well as the other reasons stated, not so applicable to operations in the field, yet it so surpasses the batteries of every other principle, as to entitle the inventor to special thanks for the successful application of a principle which it has never before been considered possible to turn to account.

To close the inquiry into the motive power, the following, as far as experiments made with some haste tend to prove, are the comparative electro-motive forces of the several principles Ward examined:—

Grove, 410; Daniell, 235; Smee, 116; McCallan, 410; Dalgleish, 344.

The zinc, iron, and nitric-acid battery is that intended by McCallan's.

Or, if we take E to represent the absolute electro-motive energy of Smee's,

3·54 E = Grove's; 2 E = Daniell's; 3·54 E = McCallan's; 2·98 E = Dalgleish's.

Now, the mechanical equivalent for producing fusion in Smee's was found to be $\frac{E}{19\frac{1}{2}}$, from which the several expressions for the other batteries may be deduced.

*Conducting Wires.*—With respect to the conducting wires, two factors are concerned in the power of resistance of any one length to the circulation of the current, namely, the metal of which it is composed, and the area of the section; the resistance varying directly as the specific resistance of the metal, and inversely as the sectional area.

Copper, it has long since been decided, is the metal whose specific resistance, where economy is taken into account, is the least; and it only remained to decide the area of the section, or the diameter of wire to be used.

Now, considering that by increasing the number of plates in series we are able to overcome any amount of resistance, it is as well to reduce the diameter of the conducting medium till the value of the copper wire destroyed (some portion must always be expended in an explosion) is reduced to a comparatively insignificant quantity, that is to say, such as would about balance the destruction of zinc and consumption of acid necessary to overcome the resistance consequent on a still further diminution.

The Gutta-percha Company supplied copper wire covered with gutta-percha, at prices from 9*l.* to 21*l.* a mile, the difference being due *solely* to the greater or less quantity of gutta-percha covering, and not at all to the weight of copper furnished. The thickest of these averaged about 250 grains a yard, the smallest about 160 grains. As the former was, of course, the superior conductor, was equally portable, and of no greater expense than the smaller size, it may be the best size for a conducting medium. It is about $\frac{1}{10}$ of an in. diameter.

This sized wire when covered with gutta-percha is very flexible, and can be easily coiled on a reel; two miles in length would easily pack in a cubic yard: its conducting power roughly stated is such that $1\frac{1}{2}$ yd. of it would be equivalent in resistance to one turn of the rheostat wire, and making this allowance, the measures before stated can be easily reduced to corresponding lengths in this wire.

The degree of covering required to ensure perfect action depends on the nature of the explosion required; if an explosion is to be made under water, when only one wire is required for completing the circuit, the most perfect covering is desirable, and the cost of the wire so covered would be 21*l.* a mile; but for any explosion on land, where a return wire is always necessary, that sold at 9*l.*, 10*l.*, and 11*l.* a mile is sufficiently isolated, especially if the wires leading to the mine are not buried under the ground, or, if buried, kept as far apart as possible. In no case would we recommend lapping the wires, leading to and returning from the mine, side by side, as has hitherto generally been done, for whatever advantage the practice may possess, the chances of failure in consequence are many. If, for instance, in burying it the spade by chance should lay bare the surface of one, it would probably also do the same with the other wire; or, again, if from extraordinary heat the gutta-percha should get soft, which it will do at a temperature of about 160° Fahr., a twist in the rope may bring the two wires together, and the covering afterwards hardening would prevent their separation; and, above all, if a fracture should take place it would be very difficult to find on which wire and whereabouts it had occurred.

Gutta-percha is the best covering for the conducting medium, as it is the only means by which perfect isolation can be obtained under every circumstance.

*Bursting Charges.*—There are two descriptions of bursting charges before the scientific world, one of which has been long in use, and in which a thin platinum wire, forming part of the circuit, is brought to such a heat as to ignite the surrounding powder; and another, the invention of Mr. Brunton. The company with whom this gentleman was connected had been in the habit of what is familiarly called vulcanizing the gutta-percha which covered the wire, to render it pliable even in the coldest temperature, and this led to the discovery of the fuze in question. By the vulcanizing process, sulphur and carbon become incorporated with the gutta-percha in a manner, so to speak, almost chemically perfect. These two act on the enclosed copper wire, and in process of time produce on its surface a species of sulphide, portions of which, when the wire is withdrawn, remain adhering to the inner surface of the gutta-percha covering. This inner surface, which before was simply gutta-percha, and therefore a non-conductor, has now a feeble power of conduction given to it by means of the minute particles of sulphide of copper and carbon. The conducting power is however very feeble, and seemingly in no two portions the same; but whatever the amount of resistance may be, if it can be overcome sufficiently to circulate such a force as will ignite the sulphur and carbon, the desired effect is obtained.

That the degree of heat, or what is generally termed quantity, required for this need not be anything approaching to that for fusing a platinum wire, may be easily conceived, if we compare platinum, which no amount of heat from a smith's forge will melt, and the elements sulphur and carbon, which are combustible at moderate temperatures; yet that the degree of resistance they offer to the passage of the current must be great, may be judged, when it is stated that 48 cells, and even more sometimes, of Grove's reduced battery are required to inflame them close to the battery. These same 48 cells would explode a mine, by means of the platinum fuze, at a distance of ¾ of a mile very readily.

In order, however, to cause any sensible current to pass through these sulphides, it is necessary to close all other channels of communication, that is, to break the circuit of the copper wires; then, with a sufficiency of power to overcome the resistance, a combustion with powder in contact will produce the desired explosion; and on this principle the bursting charge is made, a part of the copper circuit being broken and the sulphuret surrounding that part being laid bare and covered with powder.

Here, then, we have two modes of igniting powder at a distance, namely, by the fusion of platinum wire, and by the combustion of a compound which seemingly is a sulphuret of carbon and copper; in the former, the medium being metallic, and, therefore, a good conductor, requires at the same time a high degree of heat to fuse it; while in the latter, the sulphide, though opposing a very great resistance to the flow of the current, ignites even when a considerably less quantity is actually passing.

Now, bearing this in mind, and also Ohm's theory or law regulating the circulation of divided currents, namely, that the quantity flowing by each of two or more portions simultaneously is in the inverse ratio of the resistance of each, the following characteristics of these two descriptions of bursting charges, which have been *practically* ascertained, will be easily understood:—

1. To fire a platinum bursting charge, a return wire, where water cannot be made available, is always necessary, for Ward found that the resistance of ¼ of an in. thickness of ordinarily moist earth substituted for it could not be overcome by 48 pairs of Grove's, which would fire the same charge at the distance of ¾ of a mile, or through a circuit of 1¼ mile of copper wire of No. 16 gauge; and this shows that the substitution of earth for metallic wire increases the resistance so much as to diminish the quantity circulating to such an extent that the necessary heating effect is not produced.

2. Whatever number of cells—roughly speaking, for of course it cannot be accurately true—it is found necessary to arrange in series to produce ignition in Brunton's fuze at the distance of 1 ft. will produce the same effect through a copper-wire circuit of 1 mile; and an addition of about one-fourth that number will permit of one-half this copper circuit being replaced by ordinarily moist earth.

These two results show that the absolute resistance of this fuze is so great that the addition of a mile of copper wire or a large quantity of earth effects no material diminution in the quantity actually circulating; that is, if E = the electro-motive force, $r$ the resistance of the fuze, and R that of the sum of all the other resistances in the circuit, then $\frac{E}{r}$ is very nearly $= \frac{E}{r + R}$.

3. The same number of cells in series of a battery furnished by the Gutta-percha Works Company, that would ignite Brunton's fuze at the distance of 1 mile, did not produce any visible heat in the platinum wire of the other bursting charges at the distance of 1 ft.; and this will be easily under-

stood from what has been said before, for if, by increasing the resistance of the liquid stratum L, we make $F = \frac{E}{L}$ represent a force generated by one plate, which is not capable of heating platinum wire, any number of such cells in series will not heat that wire, as $F = \frac{n\,E}{n\,L + w}$ must be less than $\frac{E}{L}$. At the same time if the force required to circulate be less than $F = \frac{E}{L}$ or = F′, and L remain constant, the combination of cells in series will have the effect of diminishing $w$, and ultimately of producing the required force F′.

From this we also learn that the force required to circulate for the ignition of Brunton's fuze is considerably less than that for the platinum bursting charge, and this is still more apparent when we find, as we do, that it does not produce any sensible heat in the platinum wire, much less fuse it.

The battery that gave these results was one that was supplied by the Gutta-percha Company as the best then known for igniting these fuzes. It was a common zinc and copper arrangement, each pair 4″ × 4″, and each compartment filled up with sand moistened with acid. 100 plates were required to ignite a fuze with certainty, and even 300 would not produce a sensible heat on platinum wire; and this is due to the amount of resistance offered by the intervening stratum, in this case composed of sand and dilute acid: but as sand is no conductor, the only reason for its use is that it enables the batteries to be carried about without spilling the acid. The average resistance of the stratum of sand, supposing it to have been entirely moistened by dilute acid, when a force F was circulating, was found = about 12·8 turns at the distance at which the plates stood, and the available force a cell = 6·7 turns, making the equation representing its action $F = \frac{E}{12{\cdot}8 + 6{\cdot}7} = \frac{E}{19{\cdot}5}$. By the employment of sand, certainly not one-fourth the quantity of liquid can be used, consequently the resistance L must be increased at least fourfold, or = 51·22, which renders it impossible that the force, which we have called F, can circulate in any such arrangement. The use of sand also prevents the evolution of the hydrogen, and so reacts in controlling the electro-motive force. These figures, however, are not given as strictly correct.

4. It is easy, then, to see that the diameter and description of metallic conducting medium for the platinum charge are matters of material consequence, and its standard resistance should in all cases be known; but with Brunton's fuze it is of no consideration to know it, and in this respect Brunton's fuze presents singular advantages.

5. The isolation of the conducting medium to Brunton's fuze must be *absolutely perfect*, whether the explosion is to take place on land or in water; with the platinum-wire charge it need not be so in either. The abrasion of the covering may be so small as hardly to be discovered by the eye, and yet it will be sufficient, if in contact with the earth, to cut off the circuit almost entirely from the bursting charge. From Ohm's law for divided circuits this is easily accounted for. The resistance of the fuze being by far the most considerable one in the whole circuit, any way by which the current can return to the battery, without passing through the charge, will be taken advantage of for that purpose, by just so much the greater portion of the galvanic excitement generated.

When we consider the chances of a covering like gutta-percha—and this is the only covering that is known, which can be employed in practice, and at the same time give perfect isolation—being cut by a flint or by a workman's spade while being buried, and know that however minute the cut no power of battery will be able to overcome the obstacle it forms, or make up for the loss of fluid it occasions, the necessity for adopting some efficacious protection over the gutta-percha, before the mode of firing by Brunton's fuze can be successfully applied in military operations, will be admitted.

That this perfect isolation is not necessary for the platinum-wire fuze is well known, as, even in water, the loss occasioned by a bare wire can be overcome by extra power of battery. The reason is obvious; the resistance in the bursting charge is metallic, and consequently much less than a liquid resistance. The conducting power of iron, which is certainly not superior to that of platinum, is estimated to be to that of water as 400,000,000 to 1, and, therefore, even supposing the proportion of copper surface exposed, on the wire leading to and returning from the platinum bursting charges, to be in this proportion to the area of platinum wire, if their surfaces were brought to within a distance of $\frac{3}{8}$ of an in. of each other, which they never would be in practice, only one-half the quantity of the electric fluid would be cut off from the bursting charge; and if to the distance of 1 ft. apart, not $\frac{1}{30}$ part of the force would be arrested in its passage through the platinum wire. As anything approaching this amount of abrasion can never occur, with ordinary care, in practice, no fear of a failure from a diversion of the currents need be entertained.

The wire leading to the bursting charge having been attached to the two ends of the secondary coil, a few plates of a Grove's battery circulated a sufficient current through the primary wires. The usual contrivance of a temporary magnet, for making a breaking contact, was employed for obtaining intermittent sparks in the fuze.

With this helix, and four plates of Grove's battery 4″ × 4″, it was easy to explode a bursting charge at the distance of 1300 yds. from the operator, *the return circuit being made through the earth.* It was but necessary to leave one of the wires of the bursting charge in contact with the earth, the other being attached to the wire leading to the voltaic arrangement, with which it was connected. A wire from the other end of the secondary coil led to the earth, which, if touched, was sufficient to explode the charge. There is no doubt that this helix arrangement greatly simplifies the apparatus required for the explosion of these charges, for without it about 120 cells are required to produce with certainty the same explosion. The fact that a return wire for completing the circuit may be dispensed with is a great recommendation for the adoption of this fuze; though at the same time it must be remembered that perfectly dry earth will resist the flow of any current.

In a bucket full of dried sand Ward put two plates of copper, 1 ft. square, at a distance of 1 in. apart, and the whole power he could apply could not overcome the resistance interposed.

With respect to firing a number of charges simultaneously with each of these fuzes, the platinum charge, as may be supposed, has the advantage, for on account of the great resistance added to the circuit, where a second gutta-percha fuze is introduced, the force before circulating is materially diminished, and can only be brought up to the original strength by a great addition of power. The practice Ward had with this fuze was not sufficiently extensive to give him confidence in its application to simultaneous firing; but, to state what has been done, 120 plates of the sand battery before mentioned, or 10 batteries of 12 each, fired one charge well through a circuit of five miles of copper conducting medium, about No. 16 gauge; 96 did the same feebly; 72 could not fire it: 216 plates were required, roughly speaking, to fire two placed in the same circuit; 216 fired three in a circuit of one mile: 360 fired six; and 480 fired eight in the same circuit.

These experiments were made in Brunton's presence, the wires being under water in the canal basin; but it should be remembered that the whole of the circuit was not metallic, a few yards of the return portion being through earth and water, which however, when compared with the great extent of wire, may be considered to have no sensible influence on the result. From them it will be seen that these fuzes are capable of being exploded simultaneously when placed in a circuit; but it requires more practice to determine if they can be so trusted, and it is apparent that each additional one requires a large addition of cells. With the platinum-wire fuze, an addition of two plates for every charge inserted is all that is necessary to establish the circulation of the required force. The platinum charge possesses a great advantage over the gutta-percha fuze, in that its resistance being metallic is uniform, while that of the gutta-percha depends upon the degree of action that has taken place on the copper wire, and especially on the extent of sulphuret circuit; for its resistance is so great that an additional length of one-eighth of an inch causes a great diminution of force in circulation. This last circumstance, combined with the degree of action that has taken place, tend to make the resistance so variable, that sometimes 12 plates have been able to ignite a fuze: it is not safe to apply less than 100 plates of the sand battery. With the platinum charge two plates are always sufficient to overcome the resistance. The gutta-percha fuzes are also liable to deteriorate by exposure to the air, sulphate of copper forming where the sulphides were, and the fuze losing in consequence its inflammable properties. Several modes have been tried of making these fuzes; some requiring six months to mature, and others only half an hour; but the respective sorts seemingly present this property, that the sooner they come to maturity the easier they deteriorate. Both descriptions of fuze have their peculiar advantages. The one may be issued ready made, as an article of store, and the other would sometimes turn to account in an emergency in the field, when the store supply had been exhausted. In fact, the range of inquiry with respect to this description of fuze is very extensive, and well worthy of pursuit. It may be apprehended that such enormous distances will not be necessary in the field: as the cost of the return metallic circuit can be made up by a less expenditure of gutta-percha in procuring isolation; as the resistance of any now employed can be ascertained with sufficient accuracy and hardly any labour in a few minutes; and, as we shall show, the power required for any proposed explosions, simultaneous or otherwise, can be calculated with far more correctness and confidence than, with respect to the gutta-percha fuze, it is as yet possible to do; and, above all, as the casualties that ordinarily attend the laying out and burying of the conducting medium will have no sensible effect on the platinum fuze, while they have a most important one on the other, it seems right to conclude that, as far as our experience goes, the platinum fuze possesses greater recommendations for use in military engineering.

Having thus decided on the most suitable battery, conducting medium, and bursting charge, it remains yet to point out the rule for calculating the number of cells necessary for exploding any arrangement of charges with them, and at any distances that may be required. The length of the platinum wire of the bursting charge will, of course, influence the resistance of that part of the circuit. From practice, it has been found that a wire $\frac{3}{4}$ of an in. long gives sufficient heat, with the least expenditure of power; and it therefore seems desirable to use that length, as it is as well to adopt some one length, whatever it may be. A length of $\frac{3}{4}$ of an in., weighing 1·65 grain a yard, offers a resistance of nearly 61 turns of standard wire, which is equivalent to about 90 yds. of the selected copper conducting medium, weighing 250 grains a yard; and any extra length employed must be allowed for in the same ratio.

Referring back to the equations representing the working of the reduced Grove's battery, it will be seen that $F = \frac{E}{46}$ is assumed as the mechanical expression representing that each cell of the battery, in fair working order, may be subjected to a controlling resistance equal to 46 turns of standard wire, and yet will fuse the platinum wire in the midst of powder; and that $\frac{E}{68\frac{1}{2}}$ represents the conditions of fusion when no powder surrounds the wire; but as it is the rule for the explosion of powder which we have now to consider, the expression $\frac{E}{46}$ most concerns us, and this expression for the power in strong action, that is, during the first two or three hours, is represented by $\frac{E}{14\frac{1}{2} + 31\frac{1}{2}}$ where $14\frac{1}{2}$ is the average liquid resistance a cell, and $31\frac{1}{2}$ is the energy available for overcoming the metallic resistance.

Roughly speaking, $1\frac{1}{2}$ yd. of the established conducting medium of 250 grains a yard is equivalent in resistance to one turn of the rheostat, therefore the available energy to a cell would be equal to about 46 yds. of the conducting medium; and the resistance of a platinum wire $\frac{3}{4}$ of an in. long, and 1·65 grain a yard, being 60 turns, would be equal to, say, 100 yds. of the wire. For firing a mine at any distance when the battery is in good work, we have then this simple

rule:—Take the whole circuit in yards, including distance up and down shafts, add to it 100 yds. for every charge in the circuit, and divide by 46 for the number of cells. This is the rule that theory points out; it will not be advisable to draw it so fine in practice, but our object at present is to show the principle which regulates the calculation.

Again, when the battery has been six hours in action, $\frac{E}{42}$ and $\frac{E}{63\frac{1}{4}}$ are shown to be the mechanical expressions representing the resistance which each cell has the power of bringing under control whilst circulating a force sufficient to fuse the wire in and out of powder. Taking $\frac{E}{42}$, which concerns us most at this moment, we find by referring back that 23 of the 42 turns are consumed by the liquid resistance of each cell, and only 19 a cell are left to overcome metallic resistance, in fact $\frac{E}{42}$ being $= \frac{E}{23+19}$. These 19, expressed in turns of the established conducting medium, $= 28\frac{1}{2}$ yds. a cell. Having now therefore but $28\frac{1}{2}$ yds. of available energy a cell, instead of 46, the rule for calculating explosion must be modified as follows:—Take the whole circuit as before in yards, add to it 100 yds. for every charge placed in the circuit, and divide by $28\frac{1}{2}$ for the number of cells, and it will be seen that these two rules give widely different results; as, for instance, if a mine were required to be fired at a distance of half a mile, the former would give 41 cells and the latter 66 cells as requisite.

If at any time an economical use of cells is of consequence, it is desirable to have a ready mode of ascertaining what condition the battery is in; for it matters not what that may be, provided we can ascertain it, and apply the proper rule. Fortunately there is a very ready mode of ascertaining with sufficient exactness the power of any arrangement of cells in series at any moment, and of determining the number of cells necessary at any period between the first charging and six hours after. We have, for instance, seen that when the battery is in good action $\frac{E}{68\frac{1}{2}}$ is the force necessary for firing one platinum wire placed in the galvanometer, that double this force or $\frac{E}{34}$ will be required to fuse two side by side; similarly, a force represented by $\frac{E}{23}$ is required for firing three, $\frac{E}{17}$ for four, $\frac{E}{13\frac{2}{3}}$ for five, $\frac{E}{11\frac{1}{2}}$ for six wires, and so on; these results all depending on the figure $68\frac{1}{2}$, which at this period represents the electro-motive energy of the battery in turns of standard wire.

Whatever may be the number of wires that can be fused side by side, the resistance of the liquid stratum cannot be affected by it; and while the electro-motive force a cell remains at $68\frac{1}{2}$, the fact of being able to fuse any number of wires side by side shows that the resistance of the liquid stratum cannot be so much as the denominator of the fraction representing the force required for such fusion. For instance, if five wires can be fused side by side, the resistance of the liquid cannot $= 13\frac{2}{3}$, for if it did, the force $\frac{E}{13\frac{2}{3}}$ would be exactly balanced by the resistance, and could not circulate, if six, it cannot equal $11\frac{1}{2}$. Having thus ascertained that five wires can be fused, and not six, it would be quite safe to call $L = 13\frac{2}{3}$, and as $\frac{E}{46}$ represents the force necessary for fusion in powder, it is perfectly certain that at that moment the available energy a cell for an explosion, in turns of standard wire, cannot be less than $46 - 13\frac{2}{3} = 32\frac{1}{3}$ turns = 48 yds. of selected medium. Similarly, if but four wires can be fused, it will be perfectly safe to allow 44 yds. of selected medium a cell; or if but three, 35 yds. a cell, the resistance of the liquid at this period approaching 23 turns.

At the end of the day of six hours it has been seen that the electro-motive force has fallen in the proportion of $68\frac{1}{2}$ to 63. And the available energy a cell will be reduced as follows: if four wires fuse and not five, to 39 yds.; and further, if three wires fuse and not four, to 32 yds.; and it would not be possible to fuse five wires, with electric energy at 63, at any intervening period, but an allowance of $1\frac{1}{2}$ per cent. an hour for the diminution of the electro-motive force will give the available energy a cell at that time.

This detail has been given to show the principle of the rule and its amount or accuracy, but in practice the whole may be combined into this simple one. Previous to firing a mine, when all the plates are arranged and connected, insert five wires in the slits of the galvanometer, and place the whole series on to fuse it. In all cases it is desirable to put on the *whole* number of cells you intend applying to the explosion required, as by this means you obtain a practical proof of what that combination, with all the errors the manipulator may have committed in arranging the battery, is able to perform; and you must take care *not to touch the connection* of the battery after you are satisfied as to the power it presents for your use. If a fusion takes place, allow 44 yds. of circuit for every cell; and if the number of cells employed do by calculation cover the range, reckoning the charge as 100 yds., you may feel confident in the explosion taking place as soon as the connection is made—if there are not sufficient cells, add one for every 44 yds. over. If only four wires fuse, allow 39 yds. a cell; if only three, 32 yds.

The trial should be made with all the cells that it is proposed to use, and if any are subsequently added it should be repeated; for the more cells there are in combination, the more accurate is the result. The advantage of the trial is that the result immediately points out any mistake that has been made in charging the cells, or in arranging them, and also if that mistake is of any material consequence; and it may be assumed that the same series of this size of plates that will fuse five wires side by side, will as surely command a circuit of 44 yds. for every cell.

It is customary previous to an explosion to test the wire circuit by a galvanometer needle, to ascertain if the circuit is entire; but it seems to me equally necessary to test the power of the battery. The test explained does not require two minutes to apply, and infallibly points out the available force at that moment.

As the diameter of the conducting medium is of great importance, as well as its specific resistance, it is fortunate that the rheostat, by a mode essentially practical, enables us readily to determine the absolute conducting power of any diameter or description of wire. The mode of doing this has been explained before, and need not now be repeated; it will be sufficient to say that the probable error of a single observation with Grove's battery does not exceed 1¼ per cent. (for which an allowance can always be made on the safe side), and that any one accustomed to use the instrument could in an hour ascertain the resistance of any platinum wire that may be obtained on the spot, or of two or three miles of conducting medium, as well as every particular concerning the battery, so as to be able to apply them with certainty to explode any arrangement of charges that may be desired.

However, it is essential that every portion of conducting wire issued on service should be proved first. Let there be one description of wire kept at the depôt, which should weigh, for the sake of accuracy, somewhere near 250 grains a yd., and be covered with gutta-percha; but beyond that no precaution is necessary, nor is it essential to know the precise diameter or weight of it. A rheostat *rated*, so to speak, from this standard should be supplied to each branch depôt or headquarters, and batteries and wires similarly rated should be also furnished in quantities sufficient to meet the probable requirements.

Thus if any portion of the supplies for voltaic purposes should fall short, if the expenditure of all the platinum wire should render it requisite to employ fine iron wire, if it should be necessary to use a different conducting medium in the place of the established one, or a different battery of different acids, or, in fact, if any alteration should be rendered imperative from local circumstances, we shall have a ready mode of calculating the allowance to be made in consequence of the substitutions; and, above all, we shall have the power of comparing practice in different parts of the world, and of estimating accurately the merits of any new combinations, by a report of the experiments of half a day.

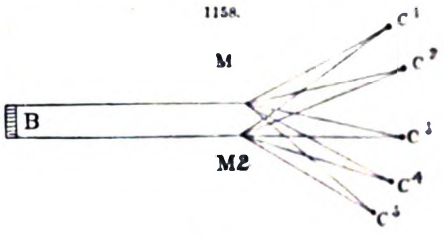
The task of perfecting the details of these arrangements must necessarily devolve on those who may be directed to continue this inquiry, as the operator merely touches on the advantages that may be attained through careful attention.

*Simultaneous Firing.*—It may be necessary to say a few words on the simultaneous firing of a number of charges or mines by one battery, and point how theory guides us to a just conclusion as to the number of plates necessary for any number under any arrangement. Reasoning, then, from the results obtained from Grove's battery, we have found,

1st. That a force represented by $\frac{E}{46}$ is required to circulate, in order to produce an explosion of one bursting charge made with platinum wire $\frac{3}{8}$ of an in. long, and weighing about 1·65 grain per yd.

2nd. It is also admitted that when any force circulates in the manner that a voltaic electric force does, the quantity passing at any one time in all parts of the circuit is the same, but that the heat developed at particular parts depends on the quality of the metal, its diameter, and conductibility. If, then, we place in the circuit any number of short platinum wires, identical in weight and length, and cause a force $\frac{E}{46}$ to circulate through it, we are led to expect that they will all fuse at the same instant, and if they do so, the explosion will also be simultaneous. Now, in order to cause such a force to circulate, it is only necessary that cells should be added capable of overcoming the resistance added by introducing each charge, or cells equivalent to 90 yds. of selected conducting medium; that is, when the battery is strong, two cells a charge, and at other times three cells a charge. This theory, if practically applicable, is productive of great economy both in cells and wire; for supposing twelve charges to be exploded simultaneously at the distance of one-seventh of a mile, or in a circuit of half a mile, by the rule before given, when the battery is in strong condition 44 cells would do the work easily with an expenditure of but half a mile of conducting medium; whereas if each had to be fired by a separate battery, we should require 22 cells and half a mile of wire for *each* charge, making in all six miles of wires and 264 cells.

At the close of the latter day Ward arranged twenty charges in a circuit of 800 yds., and endeavoured to fire them by 48 of Grove's small cells, when only fifteen exploded. Twenty charges, it will be seen by the rule given, were more than the battery of 48 cells could bear; for, allowing one cell for each 46 yds. of circuit (17), and two for every charge (2 × 20), would give 57 cells as necessary; but, as he had not that number, 48 were tried, and failed. In practice it is always best to be on the safe side of the rule, and even to add a dozen cells to the estimated quantity to make sure.




Such is the imperfect practice which Ward had with the smaller description of platinum wire in the bursting charge. We will presently sketch out the rules for guidance in making future trials; but we first notice the following mode of simultaneous firing, which has been before greatly recommended for its safety.

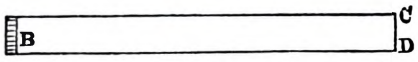
Supposing B, Fig. 1158, to be the battery, and $C_1\ C_2\ C_3\ C_4\ C_5$, five mines to be fired. At a convenient distance from B two mercury cups M $M_2$ should be placed, a wire from each mine leading

to each cup, and a pair of wires from the cups to the battery. This mode of arrangement has the advantage of connecting each mine directly with the battery, and making its explosion independent of any error that may have occurred in any of the other mines. So far it has great advantages, and we also save five pairs of wires, which would have been required to cover the five distances, B $C_1$, B $C_2$, &c., and it only remains to determine, by reference to the preceding investigation, what power of battery is necessary to explode the five simultaneously.

As it is evident that the battery B must, when the distances $C_1$ M, $C_2$ $M_2$, &c., are all equal, circulate the same amount of force through each of the bursting charges $C_1$ $C_2$ $C_3$ $C_4$ $C_5$, and as each platinum wire must be brought to a state of fusion in surrounding powder, the force to fuse all, or that flowing along B M and $M_2$ B, must be five times that for fusing one. Now $\frac{E}{46}$ in standard measure is assumed as a representation of the force for fusing one wire in powder, therefore $\frac{E}{\frac{1}{5}46}$, or say $\frac{E}{9}$, will be that required for fusing all. With the reduced Grove arranged in series no number of cells could circulate this force; because, as before stated, the liquid resistance is more than 9, or = 14½; and it then follows that, unless we can reduce this resistance L, we cannot, with the Grove in question, explode these five charges simultaneously.

There is, however, the following ready mode of reducing the amount of this resistance. Imagine a current of electricity flowing through a circuit of wire B C D, the parts of which B C, C D, and D B, Fig. 1159, being identical in all respects, will oppose an equal resistance for equal portions to the circulation of the current. Now let the portion C D be increased to double the size, or, what is the same thing, along that portion of the circuit let another wire identical with C D be placed, carrying the electric fluid from C to D concurrently with C D, and the effect will be that the resistance of the length C D of the circuit will be reduced to one-half, or, if a third wire be added, it will be reduced to one-third, and so on.

1159.




1160

Now, altering this disposition of the circuit, let us imagine one battery B, Fig. 1160, say of 12 cells, circulating a current B C D as before, having another, identical in all respects, placed alongside of it, the two zincs being connected, as also the two platinums, and the current circulating in the direction Z P D C. Banishing for a moment from the mind the idea that the electricity is being generated there, which circumstance cannot affect the reasoning, it will be seen that if the resistance of 12 cells before was 12 L, the resistance by this new arrangement *of this part of the circuit* has been reduced to 6 L; or imagining the two batteries B and B, each of 12 cells, to be now one battery, the resistance of the 12 cells of this new machine is now but one-half of what it was in the old one; and if a third battery was put alongside, the resistance of the combination would be 4 L, and so on. We can therefore make a battery, *without any more trouble than that of altering the modes of connection*, which shall give a resistance of liquid of any degree we please; and therefore we can circulate *with economy* any amount of force, or in fact form a battery suitable for *any* purpose.

In the case we have taken, we require to circulate an amount of force expressed by $\frac{E}{9}$ in standard measure, where R = L + $w$ = 9. The most economical mode, theoretically speaking, to circulate this is to make a battery in which L = 4½, leaving 4½ of standard measure for each cell's available energy; but, on practical considerations before noticed, L should be somewhat less than $w$.

The resistance of each cell of the Grove battery adoped has been shown to be about 14½. Now, five batteries arranged abreast will reduce this to $\frac{14 \cdot 5}{5}$, say 3, leaving 9 — 3 = 6 turns = 9 yds. of adopted conducting medium as the available energy a cell; and if in the case before us we suppose the distance M B to be one quarter of a mile = 440 yds., and the distances M $C_1$, M $C_2$, and so on, each = 100 yds., the mode of calculating the number of cells to produce instantaneous explosion of these five thus arranged would be: circuit M $C_1$ $M_2$ including platinum fuze = 200 + 90, then the resistance of five concurrently would be $\frac{290}{5}$ = 58; to this add 440 × 2 (= 880), giving 938, and dividing by 9 yds., the available energy a cell, will give 104 cells for the number in combination five *deep* in series, or 104 × 5 = 520 cells in all.

Now, by the other mode of simultaneous firing, a much less number of cells will be necessary: any one of these charges could have been fired by an arrangement of 30 cells with ease, and as many more introduced into the circuit at the rate of two or at most three additional cells for each charge.

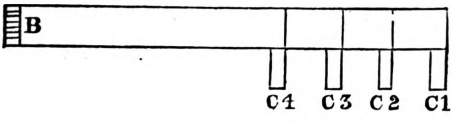
The reason for this immense difference in the number of cells necessary in the two modes is that, in the case where all the platinum wires are placed in one circuit, it is not necessary to increase the *amount* of circulating force, because the quantity flowing through one charge helps to raise the heat of all: but in the latter arrangement it is necessary to supply heat sufficient to melt five platinum wires, of one thickness, simultaneously; and as they *share* the electric

current established *between them*, five times the amount of force is necessary. If, then, an equation $\frac{E}{L+w} = F$ represents a battery in which $L + w$ are economically arranged to produce a force F, then $\frac{E}{\frac{L}{5}+\frac{w}{5}} = 5\,F$ represents a disposition for fusing five such wires. Now $\frac{L}{5}$ it has been shown can only be produced by placing five cells abreast, and as $\frac{w}{5}$, representing the available energy of a cell, is only *one-fifth* of what it was before, it requires that five times as many should be arranged in series, end on, to overcome any given resistance.

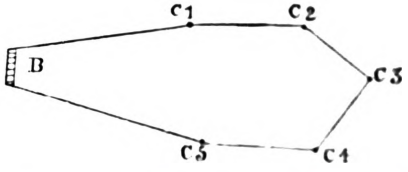
These are the only two principles of firing simultaneously that are practised, for the following arrangement is but a modification of the second mode, as will be apparent, and the same mode of calculation applies to it. We have, by the second arrangement, a mode of exploding any number of charges simultaneously, and from the arrangement itself it is evident that a failure cannot take place, for each charge will be quite independent of the others. At the same time it is very doubtful if any economy is secured by this arrangement. Supposing B M $C_1$, in Fig. 1158, to be 540 yds. as before, $\frac{540}{23} + 2$ gives 26 cells as quite sufficient for exploding that one mine, and therefore $26 \times 5 = 130$ cells would be enough to explode all five simultaneously, if *each charge* had a pair of wires leading to B. Now, to economize *four* pairs of wires along M B, or to save the trouble of laying out two miles of wire, we are obliged to employ $520 - 150 = 370$ extra cells; and it becomes a matter for consideration whether the extra expenditure of trouble and acid, at the source of supply, does not more than counterbalance the labour of arranging the wires. In fact, the first principle of simultaneous firing, namely, that of placing all charges in one circuit, is the *only* economical mode, and that it requires but a knowledge of the principles which we have endeavoured to make clear, without any finessing in practical details, to ensure success with it on every occasion. The great cause of failures in simultaneous explosion has been the want of sufficient power; and if any one will take the trouble to examine, on the principle of Ohm's theory, the statistics of recorded failures, they will see that they all thus occurred from a manifest want of power; so that instead of disappointment at their want of success, they will wonder how they ever succeeded.

It has generally been the habit, as a matter of precaution, to solder two wires side by side in a bursting charge, in case one should break; would any one unacquainted with Ohm's theory imagine that if a battery, economically constructed for fusing one wire, were used to fuse two side by side, it would not be able to produce even visible heat in either of the two, or, in fact, that it would require four times as many cells (arranged as explained before) to fuse these two wires? yet sometimes three or four have been so placed. Occasionally two charges are placed thus, $C_1$ $C_2$, Fig. 1161, in one powder-box, each ($C_1$ and $C_2$) having two platinum wires. If a battery were economically constructed to fuse one such wire, it would require nearly sixteen times as many cells to fuse the four.

1161.




1162




Suppose, again, Fig. 1162, that a number of charges are arranged in a circuit thus, each with two precautionary wires, and that while the battery is powerful enough to fuse the double wires all round, one of the two wires in one charge ($C_1$) is broken by some mishap; it is then rendered *positively certain* that, however strong the battery power may be, this ($C_1$) will be the only charge which will explode, for the *one* wire left in it will fuse before the other pairs will arrive at any visible heat. Ohm's theory explains the cause, and points to this as the certain result.

Again, the conducting wire hitherto used for explosion has been generally ¼ of an in. thick, and the platinum wire in the bursting charge sometimes 1½ in. long; now, can it be supposed that it was generally known that the introduction of one such bursting charge in the above circuit was equivalent to adding 1200 yds. of the thick conducting medium, or that an equivalent to this resistance in cells was ever added to compensate for the diminution of force?

These, and many other extraordinary results depending on the principles regulating the circulation of a voltaic current, have given this agent the character of extreme mutability and uncertainty, which it does not deserve, as they were the consequence of an imperfect knowledge of those principles.

From what, then, has been shown above, as the result of the use of a second platinum wire in the bursting charge, it will be apparent that Ward condemns its application; since in firing charges simultaneously in a circuit it is worse than useless, and is indeed ruinous in its effect. The precaution being resorted to, implies a belief that in case of a single fracture in any one charge, a second wire is at hand to complete the circuit and ensure an explosion of all: but the reverse is the case, as has been shown; and the second wire, the first being fractured, ensures that this charge is the only one which will explode: and yet the usual testing of the circuit by a galvanometer needle, previous to connecting with the battery, will delude one with the hope that all is right; whereas, if only one wire had been used in each charge, the fracture would have been

made apparent at once by the breaking of the circuit, and thus a warning given to repair. In no case should we attempt to place more than one platinum wire in a bursting charge, and that charge should be *only* connected with a pair of conducting wires leading to the surface or end of the tamping: place a second charge, if it is thought desirable; and before finally connecting *either* of them with the wires intended to lead to the battery, test each by the galvanometer to see if the circuit to that point is complete, and then connect only one of them to the main wires leading to the place from which the mine is to be fired.

It will be seen that for whatever purpose voltaic agency may be required, and whatever principle we adopt to circulate the amount of current required, there is a certain size of plates which will do it to the best advantage, depending on the mechanical equivalent representing the value of that force. In the present case the force required was found to be best produced by a Grove's arrangement of the size submitted. When a Smee was tried, though from its simplicity it was preferable to a Grove, it was found that it choked itself, as it were, in its endeavours to circulate the amount required, and consequently its circulation was not constant and not suitable for our purpose; at the same time its electro-motive energy being low, more bulk was necessary for producing any effect. Daniell's battery certainly circulated a constant force of the degree required; but it was inferior in electro-motive energy to Grove's, and, being at the same time more complicated, was rejected, and so with the others.

We have shown that the simultaneous explosion of any number of charges of powder can be obtained, if we can at the required moment establish the flow of such a constant current of electricity as shall produce a fusion heat in every platinum wire placed in the circuit.

It is advantageous, however, that this circulation should be produced with the utmost economy, consistent with certainty; and we have shown that the economical consideration is theoretically satisfied when (E representing the electro-motive energy of the combination, L the resistance of the liquid, $w$ that of the wire, $n$ the number of plates, and F the required amount of current) in the equation $F = \frac{n\,E}{n\,L + w}$, $n\,L = w$, or $L = \frac{w}{n}$; but that practically, for reasons given, L should be somewhat less than $\frac{w}{n}$, the expression $\frac{w}{n}$ representing the available energy to each cell of the voltaic combination.

Now, the battery submitted has been constructed to satisfy these conditions, with the platinum wire which Ward recommends. But it will be evident that any alteration in the amount of current required to circulate would require a corresponding modification of the battery. For instance, if a platinum wire double the thickness of that recommended were substituted, more heat would be required to fuse it, and therefore a greater current must be caused to circulate. This can only be brought about in the equation $F = \frac{n\,E}{n\,L + w}$, where E and L are constant, as they are in any *determined* form and principle of battery, by a diminution of $w$; and if this diminution reduces $w$ in value below $n\,L$, the amount of current required is no longer economically circulated. Nor can it be so till the value of L is also reduced, the principal mode of effecting which is by enlarging the size of the plates. The *diameter* of the platinum wire is therefore an *essential* consideration in determining the size of the plates in any voltaic arrangement to produce its fusion, as very small differences in the diameter of the platinum wire will lead to gross errors in calculating the number of cells necessary for an explosion, and uniform success can never be obtained in the field if the platinum wire has not been carefully selected, and tested as hereafter suggested before its issue from store.

The *length* of the platinum wire employed in the bursting charge is not a matter of the same importance, as a battery of the same sized plates can economically circulate the force required through any length of platinum wire. For it must be borne in mind that by adding lengths of wire we do not call on the battery to circulate a *greater amount of force*, but merely to overcome a *greater resistance* to the circulation of the *same* amount, which can readily be done by increasing the number of plates in series. For if in the equation $F = \frac{n\,E}{n\,L + w}$ we increase $w$ to $w + a$, and so diminish the value of F, we can immediately restore the equation to its former value by adding cells $= \frac{n\,a}{w}$, and the force F will circulate as economically through a resistance $w + a$ by the combination expressed by $\frac{\left(n + \frac{n\,a}{w}\right)}{\left(n + \frac{n\,a}{w}\right)L + w + a}$ as it did in the first case through $w$ by the combination of $n$ cells.

It is thus quite open to any future operator with the battery submitted, to introduce any lengths of platinum wire into his bursting charge, merely remembering to employ the thickness recommended, namely, 1·65 grain a yard; though $\frac{3}{4}$ of an in. is sufficiently long for all purposes, and possesses the advantage of less liability to fracture than greater lengths.

With respect to the copper conducting medium, that weighing 250 grains a yard, covered with gutta-percha, is recommended; but it is not *essential* that any particular metal should be employed, or that the wire should be of any particular weight, as we have described a ready mode of ascertaining the resistance, in standard measure, of any material of any length.

*Mining Operations for Blowing Down the Cliff near Seaford, on the Coast of Sussex*, 1850: *by Major-General John F. Burgoyne.*—Along the coast of Sussex the banks of shingle afford protection to the rich low lands within them from the encroachments of the sea.

The shingle, however, is in a gradual but irregular state of movement from west to east, and

at times a great impression is made on particular parts, that would lead to much damage, if not arrested by projections of timber and planking, between high and low water marks, termed groins. These groins are very expensive, and their useful effects extend but for a short distance.

William Catt, whose family have considerable possessions in the plain between Newhaven and Seaford, a distance of about three miles, considered that by constructing a very substantial groin on a large scale under the cliff near Seaford, which is at the east extremity of the plain above mentioned, and the foot of which cliff was washed by the sea at high water, and thus stopping the progress of the shingle, it would have some influence in protecting the whole extent of the beach to Newhaven.

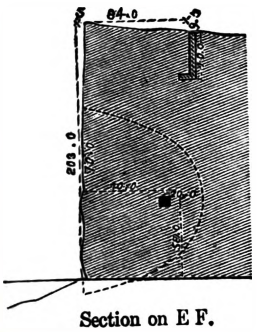
He also considered that the most efficient, lasting, and economical mode of establishing such a projecting obstruction would be by throwing down the cliff, which was nearly perpendicular, and about 200 ft. high, on to the beach, by a great explosion of gunpowder.

In the main feature of the application of the two great charges, there was no difference in principle between them and the three, though there were some in the proposed modes for carrying it out, as will be subsequently explained.

The plan finally adopted was to lodge two large charges, each of 12,000 lbs. of powder, 120 ft. asunder, with lines of least resistance of 70 ft. to the face, and 58 ft. above the level of the foot of the cliff.

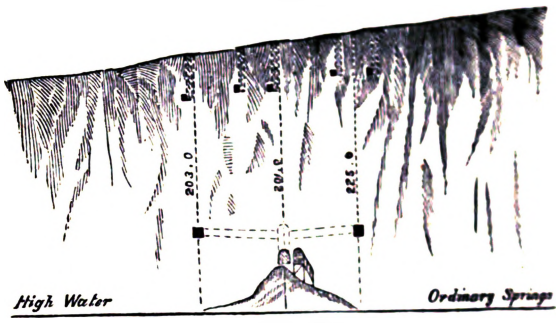
Five smaller charges, of 600 lbs. each, were to be placed in rear, Figs. 1163 to 1168, at a higher

1163.




Section on E F.

1166.




Elevation.

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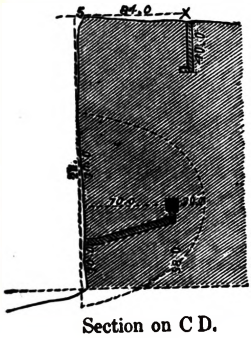


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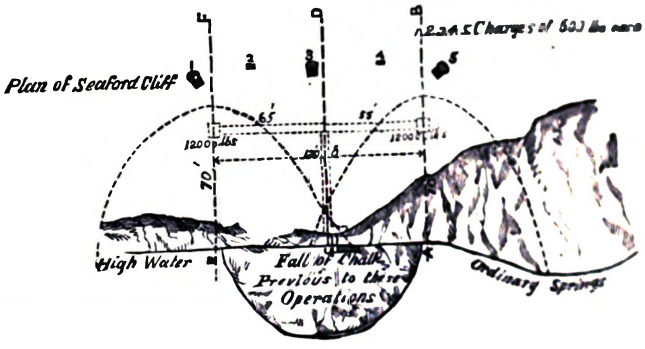
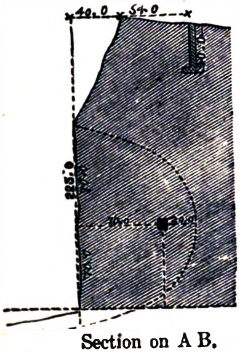



1165.




Section on A B.

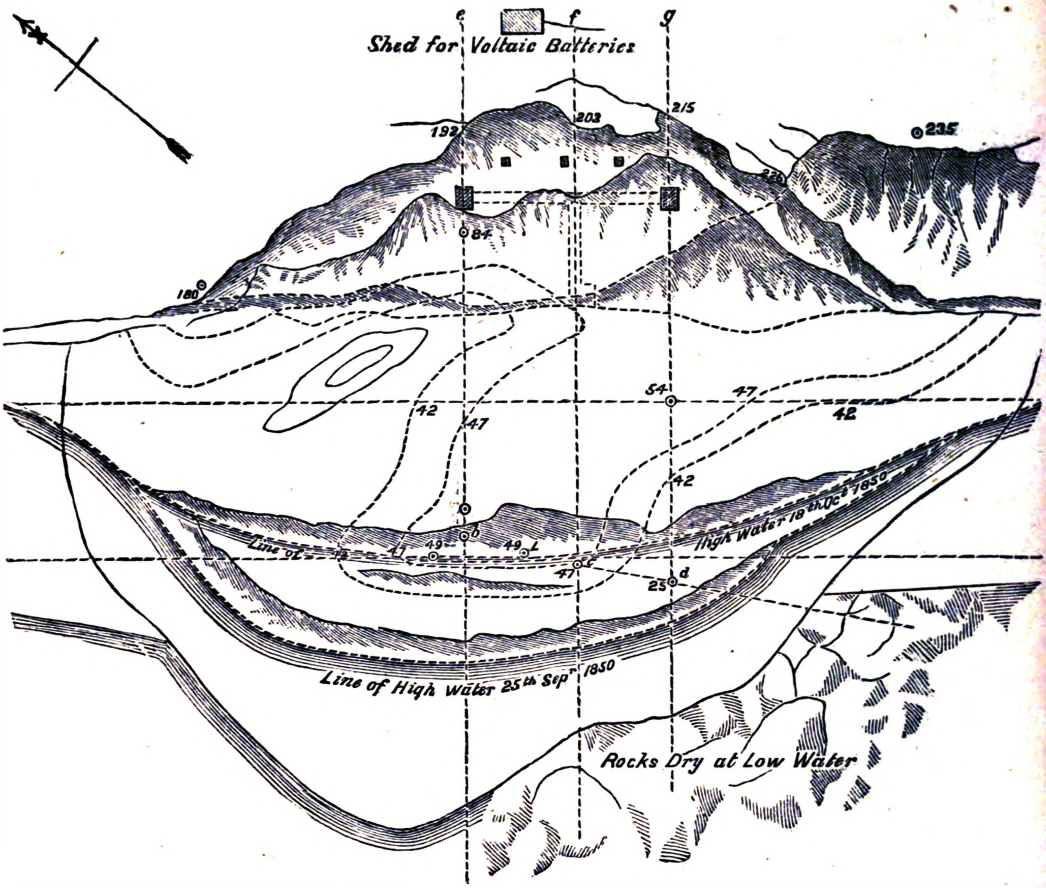
1168

level, to clear that part from overhanging remains; and the whole to be fired by voltaic batteries, the two main charges first and simultaneously, and the five smaller ones immediately after. In consequence of not receiving in time a supplementary demand of gunpowder, only three of the smaller charges were loaded.

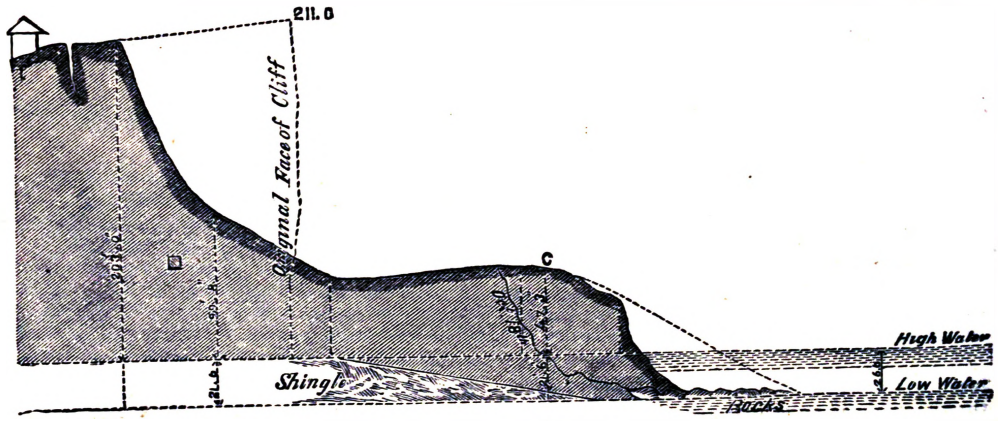
The circuit of the wires connected to the two great charges was completed at the batteries, and on the instant the ignition of both took place, throwing down the face of the cliff for a length of 500 ft., and to the rear 15 or 20 ft. beyond the five shafts, so as to bring down and bury the three upper charges unfired, cracks and fissures extending nearly to the shed in which the batteries were placed.

Figs. 1169 to 1174 show the result of the explosion of these two mines; and on the sections is also described the effect produced by the action of the sea upon the mound formed by the fall of the cliff.

1169.

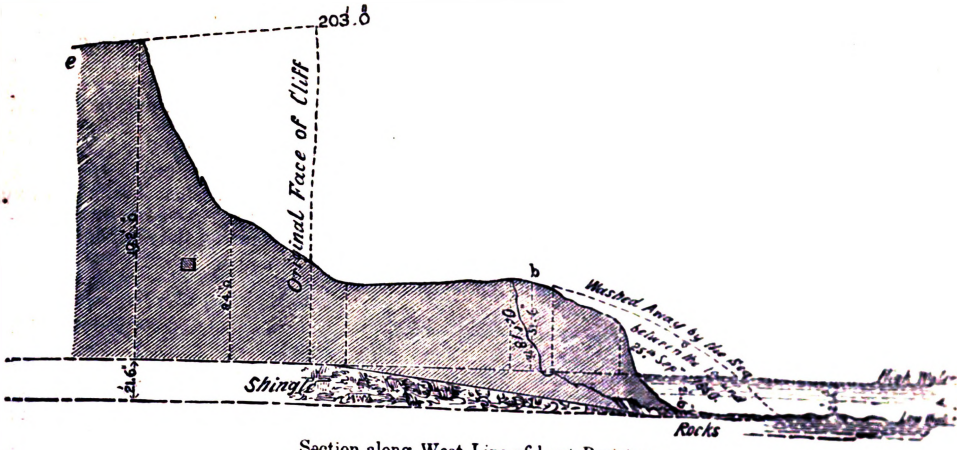



1170.



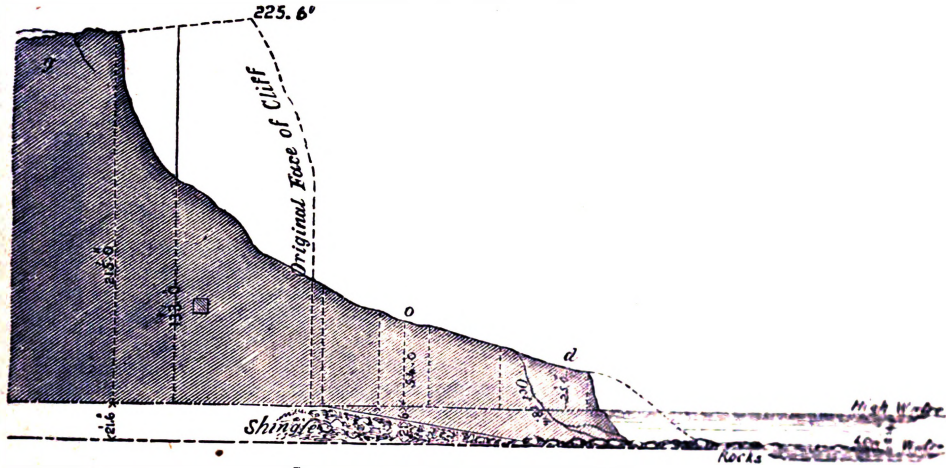

Section through Centre Line of Gallery.

1171.



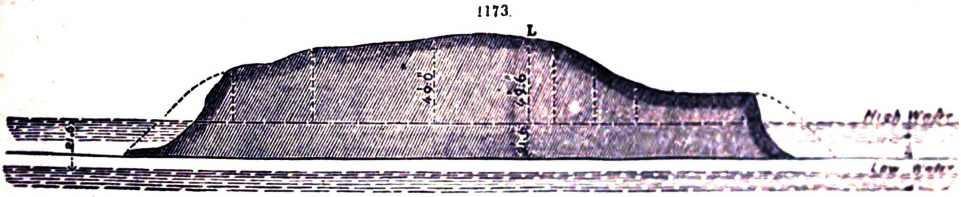

Section along West Line of least Resistance.

1172.



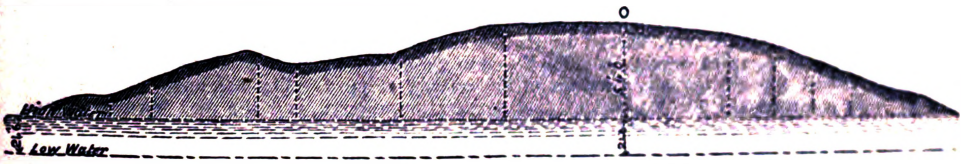

Section through East Line of least Resistance.

1173.




Section through L at right angles to Lines of least Resistance.

1174.



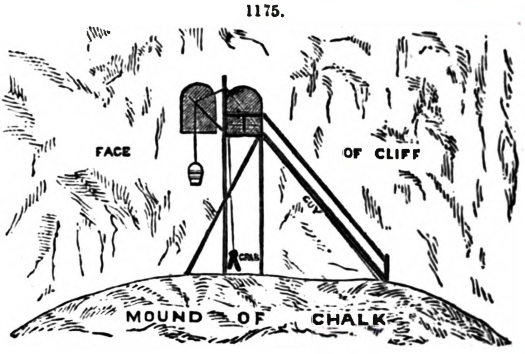

Section through O at right angles to Lines of least Resistance.

The projection of the mound, as first thrown out, was about 300 ft.

The mass thrown down, according to dimensions taken the day after the explosion, was about 200,000 cub. yds., or 292,000 tons nearly, at 121 lbs. the cub. ft., which was found by actual trial to be the specific gravity of the chalk.

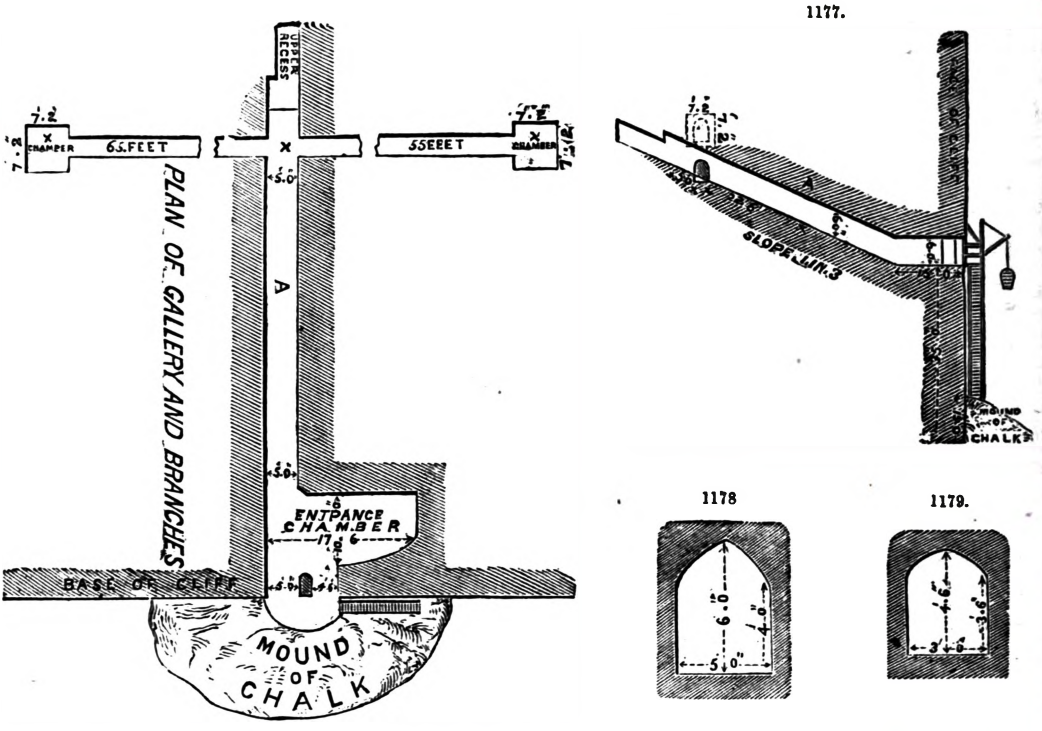
*Mining Operations at Seaford.*—The opening made in the face of the cliff for the commencement of the central gallery, by which both the chambers were reached, was 35 ft. above the high-water mark (ordinary spring tides), which at this spot was the level of the beach at the base of the cliff. It was commenced from a rough stage supported by scaffold poles, and reached by a common ladder, the stage being necessary in consequence of the impossibility of making any impression on the face of the cliff by men working on the ladder itself. The cliff is composed of a very compact chalk, 121 lbs. to the cub. ft., dipping to the north at an inclination of about 15°, and intersected by veins of flint at intervals of about 15 or 20 ft. Its height was at the site of the western mine 203 ft., and at the other 225½ ft., above high-water mark. The section at the first of these spots was nearly vertical; for the whole height at the second it was only so for about 140 or 150 ft. A mound of chalk, that had fallen a few days before just at the spot, afforded, when levelled on the top, a base 14 or 15 ft. above the beach, on which to erect the scaffolding. As soon as the men had penetrated a sufficient distance into the cliff to be able to work in security, the scaffolding was strengthened, and a convenient platform with a step-ladder constructed for use during the remainder of the operations, Fig. 1166. To this scaffolding was also fixed a crane-post and derrick capable of lifting nearly half a ton, by means of which the sand-bags and chalk used for tamping were raised to the mouth of the gallery by a crab on the top of the mound. See Figs. 1175 to 1177.

1175.




At the entrance, a cave of the dimensions shown by Fig. 1176 was formed, for the purpose of keeping all tools and materials out of the way of the men working at the gallery, and this space subsequently proved of the greatest service, as a depôt for the powder, sand-bags, and chalk, before they could be

1177.




1178



1179.



passed along the gallery and branches. Similar advantage was found from a recess, Fig. 1176, at the end of the central gallery, formed by its prolongation, originally as the mode of arriving at the spot where a third service of 2000 lbs. was proposed, which was afterwards considered unnecessary, and the further advancement of the gallery stopped. The use made of these two depôts fully compensated for the cost of their excavation, though, had the rock been of a hard nature, smaller spaces, particularly with reference to the upper recess, would have answered the purpose, and would have been advisable on the score of economy.

The men employed driving the gallery and branches worked in reliefs for the whole 24 hours. For the gallery, three reliefs of four men each were told off; and subsequently for the branches three reliefs of six men for the two, which were carried on for the most part simultaneously. The hours for relieving were 6 A.M., *noon*, 6 P.M., and *midnight*, excepting at periods when the high spring tides prevented the relief passing a projecting part of the cliff at the proper hours, when arrangements were made to equalize the extra time the men were consequently employed. The

work was hardly ever interrupted between 6 A.M. on the Monday and 6 P.M. on Saturday. By compelling each relief to be in barracks six hours before their turn came for work, the men were always fresh at the commencement of their time; and as the working pay was good, and the best miners were thus employed, the average amount of work performed by night fully equalled that by day.

The dimensions of the entrance gallery are given in Figs. 1176, 1177. The content was 47½ cub. yds.; the rate of progress about 16 cub. yds. in the 24 hours.

The main gallery of the section given in Fig. 1178 had an area of 27 superficial ft., so that each lineal foot gave 1 cub. yd. of excavation. The average rate of progress was 8 lineal ft., equal to 8 cub. yds., in the 24 hours.

The branches, of the dimensions given in Fig. 1179, had a section of about 12½ superficial ft.; the rate of progress of the two was at first about 16 ft. = 7·4 cub. yds. in the 24 hours, six men, as before stated, being employed in each relief, instead of four, as in the gallery; but as the distance from the entrance increased, this rate was not maintained, the latter portions averaging little more than 13 ft. in the 24 hours.

| | Cubic yards. | Number of Hands employed. | Cost per cubic yard. | Average number of Men in the three Reliefs. |
|---|---|---|---|---|
| Entrance chamber .. .. 47½<br>Main gallery .. .. .. 61½<br>Branches .. .. .. .. 55 | 164 | 440 | 2*s.* 4*d.* | 12 to 18 |

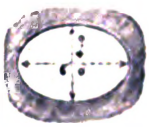
From the foregoing data, the general rate of progress of the works mentioned above may be assumed at 9 cub. yds. in the 24 hours, by five men constantly employed day and night.

In comparing the progress of the gallery and branches, it appears that the former advanced at the rate of 8 ft. in the 24 hours, and each of the latter, though less than *one-half* the area, at an average rate of only about 7½ ft. in the same time. The increased distance of the branches from the entrance would partly account for this difference; but it is, in a great measure, to be attributed to the slow progress made by miners when working to a disadvantage in a very confined space. Had these branches been 5 ft. 6 in. high and 3 ft. 6 in. or 4 ft. broad, it is probable that they would have been completed in rather less time than was occupied by the smaller size adopted, particularly as no gunpowder was used; the subsequent tamping would, however, have been proportionally increased.

The chambers for the two lower mines were cubical, the side of the cube being 7 ft. 2 in., and giving a content for the two of 27 cub. yds., Fig. 1167. The time occupied in their excavation, and in squaring their floors and sides to receive the joists and uprights to support the rough planking with which they were lined, was about 138 hours, making the rate of progress only 4 cub. yds. in the 24 hours.

The five shafts sunk for the five mines of 600 lbs. each, intended to have been fired simultaneously, *directly* after the ignition of the lower mines, were each 40 ft. deep, and of the section shown in Fig. 1180 having an ascent of about 19 superficial ft. The total content of the five was about 140 cub. yds.

1180.



Three men were generally employed upon each shaft. The stuff brought up was piled round the mouth of the shaft, ready for tamping, and no gunpowder was used, the chalk being of a much softer character than in the gallery, and not intersected in the same manner with flint. The task set to each gang of three men for the greater part of the work was 2 ft. 6 in. for every 6 hours. The average rate of progress for the first three shafts was 3 ft. 7 in., equal to nearly 2½ cub. yds. a day. The two last shafts, which were only decided upon within a few days of the explosion, were carried on during the night by reliefs. Their progress in the 24 hours was nearly 6 ft. = about 4¼ cub. yds. each shaft.

The returns at the bottom of the shafts, and the chambers for the powder, were as shown in Fig. 1181. The difficulty of working in so confined a space, and the trouble of squaring the returns accurately so as to admit the boxes containing the powder, were the causes of great increase in the expense.

1181.

The *directions* of the gallery and branches were laid out by a theodolite, with reference to a line assumed as parallel to that joining the centres of the two charges, fixed during the previous survey of the ground, and the inclination of their floors was tested by a mason's level, the miners being provided with a rough level adjusted to the required slope, to direct them during the progress of the work.

The tools used in the main gallery were the common miner's pick, and a large shovel, for which, in the branches, a mining shovel, 2 ft. 3 in. long over all, was substituted. Wheelbarrows were found more manageable in the gallery than miners' trucks, which, owing to the very great inclination at which the floor was driven (1 in 3), were very difficult to hold back when descending the slope filled with chalk, and to draw them up empty. In the branches, which had a rise of 1 in 9 to 1 in 10, trucks were always used, the recess at the end of the gallery, already alluded to, being found very useful for turning them and for keeping tools out of their road.

*Ventilation.*—The air was so pure in the whole of the galleries, and even in the chambers, that, excepting when the miners were actually at work and the candles burning, no artificial ventilation was required; had any quantity of carbonic acid gas been present, it would, owing to the steep

inclination of the main gallery, have flowed outwards along the floor towards the entrance, and its place have been supplied by a stream of fresh air along the roof of the gallery. In the branches this effect would have been much lessened, from their more gradual rise; and in the chambers, which were sunk below the level of the floor of the contiguous branches, the heavy gas would have settled immediately; but in this instance the air on the floor of the chambers appeared as pure and light as at the entrance. The air-pump by which the ventilation was effected had been used for exhausting the foul air at the bottom of a deep well sunk in the neighbourhood of Brighton; and, by mounting it upon a rough stand, it was made available in the gallery and branches. The tube, secured to the wall about 3 ft. above the floor, was, for the whole length of the gallery, part of the old wooden pipe that belonged to the air-pump; but in the branches, gutta-percha tubes, of $2\frac{3}{4}$ in. diameter and $\frac{1}{16}$ of an in. thick, were made use of.

By adding length after length to these, as required, the hot impure air breathed by the miners at work was drawn off by the air-pump, which, in fact, was all the ventilation needed. Had the air become foul as the miners advanced into the cliff, this air-pump would not have been sufficiently powerful for the purpose; to be prepared for which contingency, arrangements were made for the use of a blowing apparatus from a foundry at Brighton, which, however, was never required.

The gutta-percha tubes weighed about $3\frac{1}{4}$ oz. a foot run.

*Lighting the Galleries and Chambers.*—During the progress of the gallery and branches, the miners worked by the light of candles, in the accustomed manner; but to avoid any risk of accident from the use of lamps during the operation of loading the mines, fixing the bursting charges, and laying and securing the copper wires leading from them, a contrivance was resorted to for lighting the chambers by reflection from plates of bright tin tacked upon deal frames, which plan was previously tried and found to answer perfectly during their excavation. This method originated in a suggestion of Colonel Lewis, founded upon a mode he had practised of obtaining light in a magazine, by reflection from the painted copper door of the building. A board of about 4 ft. square was first covered with bright sheets of tin, and fixed at an angle of 45° with the direction of the centre line of the main gallery, at the spot where the branches turned off nearly at right angles. The light thus first obtained by reflection from the white chalk was very feeble, and hardly perceptible near the extremity of the branches, excepting at one short interval in the day when the sun was nearly in the line of the gallery, and its scattered rays were reflected from the sea (particularly when calm) up the slope; and the smaller reflector was then placed just outside the mouth of the gallery, in such a position as to catch obliquely the first rays of the sun that the overhanging cliff allowed to visit the spot, which was between 10 and 11 A.M., from which hour till sunset, by occasionally moving the outer reflector and adjusting it like a heliostat, to throw the direct rays it had attracted upon the set of plates at the upper end of the main gallery, a brilliant light was reflected along the branches and into the chambers, where the smallest and most indistinct writing was as legible as it would have been in broad daylight. Had the operations extended over a longer space of time, this outer reflector would have been fixed in a frame, and means contrived to render the adjustments in any way required more easy; but, for the short period it was needed, a rough plank to support it, and two or three sand-bags to retain it in the required position, were found sufficient.

*Loading the Mines.*—The gunpowder (24,000 lbs.) used for the lower mines was supplied at the lowest rate at which the Battle Mills had offered to furnish merchants' blasting powder, of good quality, but inferior in strength to cannon powder in about the ratio of 9 to 13.

It had been made up in flannel bags containing 10 lbs. of powder, nine of which bags were packed in each of the barrels, which were lined with zinc cylindrical cases, having lids fitted to openings on the top, rendered impervious to moisture by a thick coating of waterproof composition. These were sent round to Seaford Bay in a sloop, and landed, almost immediately after the arrival of the vessel (soon after low water), on the beach, before one of the martello towers which had been prepared to receive them until required for use. The whole number of barrels, weighing nearly 130 lbs. each, were carried by hand up the beach, and stored in the tower. The powder required for the mines at the bottom of the shafts sunk above the cliff, which did not form part of the original project, was not applied for at the time that the first quantity was dispatched, and, owing to some delay, did not arrive at Seaford until within two days of the time fixed for the explosion, so that it was only possible to load three of the five mines of 600 lbs. each that had been prepared.

The distance from the tower to the entrance of the gallery, nearly three-fourths of a mile, rendered it necessary to employ three carts to assist in moving the powder along the beach, on account of the time that would have been consumed in conveying all the barrels to the spot upon hand-barrows. A portion of the men were, however, so employed with nine barrows, and a party of thirty sappers, under an officer, were told off for this work, and for carrying the powder barrels up the ramp leading to the foot of the ladder, and passing the bags up the steps into the entrance chamber.

As rapidly as the barrels were brought to the top of the mound at the foot of the ladder, they were opened, and the bags passed by hand up the steps by men stationed at proper distances upon them, the convenient size of the bags enabling this to be performed with great ease and rapidity; and by the time the men went to dinner, one-third of the powder had been piled up in the outer recess, upon tarpaulins previously laid to receive the bags. After dinner, part of the men (twelve) were employed passing the bags up the gallery to the inner recess, also by hand, the men being stationed between 5 and 6 ft. apart, along one of the walls, and the gallery lighted in the manner already described.

Later in the afternoon, the men who had been occupied with the powder barrels were made to line one of the branches, sitting down with their backs to the side of the branch, and passing the bags from hand to hand to the chamber, where they were built up in a compact form, under the eye of one of the officers; the chamber having been previously floored, and lined to the height

of 5 ft. with rough planks, fastened to uprights by copper nails, to prevent the powder from coming in immediate contact with the chalk.

When one-half of one chamber was completed, the men were transferred to the other branch, and both chambers were loaded with half their quantity of powder, the whole time occupied by the above operations being only 6½ hours. Two sentries were then mounted at the entrance of the gallery, and on the following morning the work was recommenced, and the loading entirely completed by half-past 4 P.M. Before leaving work the remaining sand-bags were all filled, and about ninety of these hoisted into the mouth of the gallery by means of the derrick, and taken up to the upper recess, to be in readiness for commencing the tamping as soon as the bursting charges should have been fixed, and the first portion of the wires leading from them secured from any risk of being moved or injured, which was effected by passing them through tubes drilled in strong pieces of scantling, secured across the entrance to the chambers, and fastening them by wooden plugs, and afterwards leading them along the floor of the branches in grooves cut in narrow strips of plank, covered by other pieces nailed over them with copper nails.

The whole of the operations detailed above, from commencing to move the powder from the tower to the completion of the loading of both the mines occupied 3 carts and 30 men for 11 hours, and 12 men afterwards for about 4 hours.

The lines of least resistance of each mine being exactly 70 ft. and the charge 12,000 lbs., the proportion the latter bore to the cube of that line was about $\frac{1}{28}$, rather more than was originally proposed ($\frac{1}{35\cdot2}$). $(70)^3 = 343000$ and $\frac{343000}{28} = 12250$ lbs.

*Tamping.*—The materials used for tamping in the galleries were sand-bags (filled, some with dry chalk, but the greater part with sea-sand) and lumps of chalk. The sand-bags, only 600 of which were supplied, extended about 30 ft. from each chamber along the branches, the remaining length of which, as well as that portion of the main gallery which it was considered advisable to fill up, being completed with chalk hoisted from below by means of the derrick, in large baskets containing 6 bushels, weighing about 9 cwt. The greater part of the sand-bags were lifted into the gallery in the same manner by slings, five or six together.

In the shafts above, the tamping consisted merely in shovelling down the stuff that had previously been drawn up and piled round the opening, the charges not being sufficient to create apprehension of their producing any effect upwards, the line of least resistance in that direction being 40 ft.

The sand-bags filled with dry chalk, free from any particles of flint, were used in the branches for blocking up each of the chambers, and extended about 8 or 10 ft. from them, so as to prevent the possibility of any damp reaching the powder from those filled with wet sand, which were afterwards built in promiscuously with the others.

Large blocks were built across at intervals, and the finer stuff thrown in behind and rammed sufficiently to make a tolerably compact mass, the wires from the bursting charges being secured from injury during the operation by the manner in which they were enclosed in the grooves already alluded to.

The extent of the tamping is shown in Figs. 1176, 1177, and occupied from 18 to 20 men for three days, as also 12 men for one night. The distance from the crossing of the branches down the gallery to the spot where the tamping was discontinued, was only 20 ft. 6 in., which, though not what would be generally considered necessary with moderate charges, the point A being considerably less than the length of the line of least resistance from the centre of one of the mines, was thought sufficient; the section of the gallery being quite insignificant, when the enormous expansion that would be caused by the explosion of the two charges was taken into account. The result proved that this idea was correct; indeed, it is probable that the effect would have been the same if the main gallery had been left entirely open.

In the branches the rate of progress with sand-bags was about 12 ft. the hour, rather more than 100 sand-bags being required for every 10 ft.; they were passed along nearly in the same manner as the powder, the men being necessarily placed at less distances apart, and the branches lit as before, by the tin reflectors.

With loose chalk, the rate in the branches was 7 to 8 ft. an hour, equal to about 3¼ cub. yds., the section being 12½ superficial ft.

In the main gallery the rate of progress for the distance tamped, 30 ft. 6 in., equal to 30¼ cub. yds., was about 4 ft. 8 in., equal to 4·7 cub. yds. an hour.

The above statement of the number of men employed and the rates of progress, includes those working at the derrick and passing the sand-bags and chalk up to the party at work.

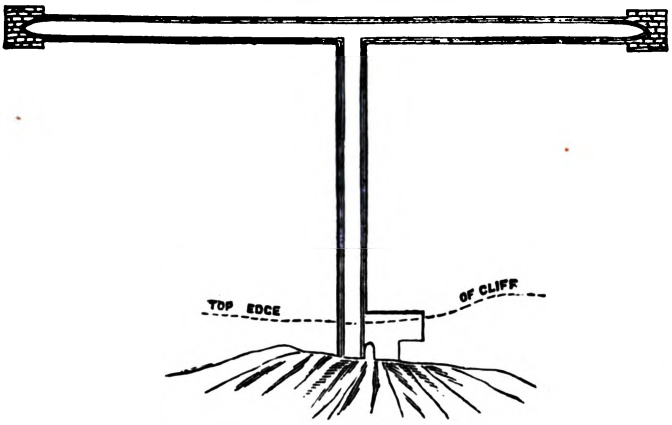
In passing the sand-bags and chalk to the end of the branches from the entrance chamber, from 20 to 24 men were required; from the upper recess, which was also used as a depôt for these materials, 12 men were found sufficient for passing on the sand-bags, and tamping.

At the derrick seven men were employed—two at the crab, three collecting chalk and filling below, and two emptying the basket above, which was in this manner loaded with six bushels of chalk, lifted a height of 22 ft., and returned in 4½ minutes. The same quantity carried up the ladder upon men's shoulders in half-bushel baskets occupied about six minutes with the same number of hands. Another advantage in favour of the derrick was, that there was no difficulty in continuing the work for the whole day; whereas the men could not have stood the fatigue of carrying the baskets up the steps for any length of time.

*Description of the Voltaic Battery.*—The position of the mines above and below is shown in Figs. 1182 to 1185. The position of the battery house, that is, the shed where the voltaic batteries were placed, and to which the conducting wires from the mines led, is also drawn in Fig. 1185.

The conducting wires from the large mines were brought up the face of the cliff, and then into the battery house.

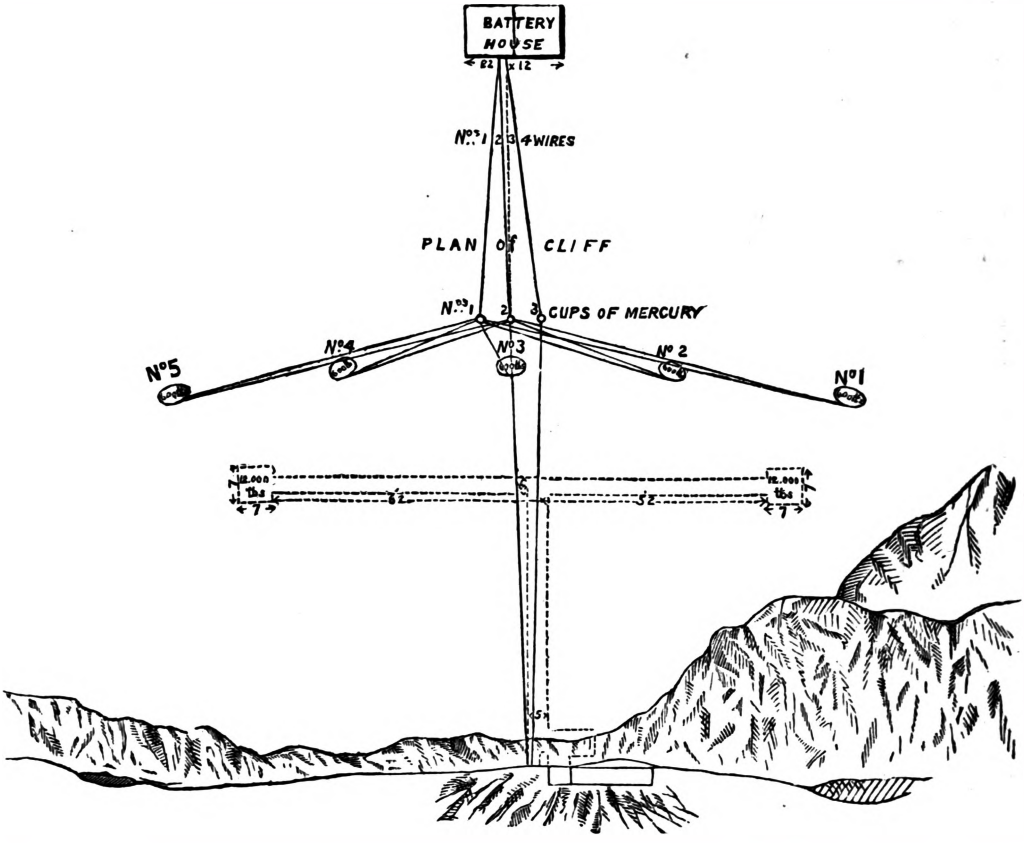
1182.




Plan of large Mines below and Galleries leading to them.

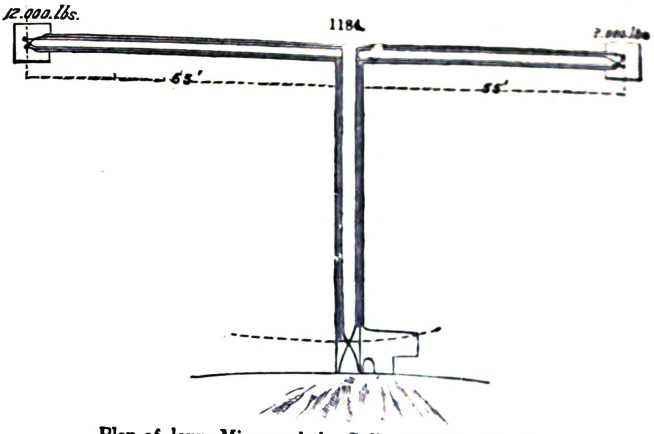
The wires on coming from the entrance of the gallery are passed up the face of the cliff, and are represented in Fig. 1167 by Nos. 2 and 4 wires.

1183.




Nos. 2 and 4 wires lead to the charges below. Nos. 1 and 3 are connected with the five mines above through the interposition of the mercury cups. On the word to *make ready*, Nos. 1 and 2 are attached to one pole of the battery, Nos. 3 and 4 being held one in each hand. On the word *fire lower mines*, No. 4 is connected to the other pole of the battery, and the lower mines explode. On the word *fire upper mines*, No. 3 is connected to same pole as No. 4, and the five upper ones explode. If instantaneous explosion of all mines be required, Nos. 3 and 4 should be previously tied together, and on touching the other pole of the battery all the mines would explode simultaneously.

It was originally intended to have fired the large mines below simultaneously by one battery, arranging the conducting wires as shown in Fig. 1183, that is, the wire proceeding from the battery was to have been carried directly to, and connected with, the bursting charge of one of the lower mines; from this, again, a conducting wire proceeded to the bursting charge of the other, which again was connected by the same means with the other pole of the battery. The whole circuit by this arrangement would have been about 360 yds. Subsequent experiments have proved that it would have been successful. When the time fixed for the explosion drew near, doubts were expressed in influential quarters of the safety of the plan, and as, from want of time, there was no means of proving its practicability by a sufficient number of experiments to remove all doubts, it was thought advisable to adopt the old method of firing each lower mine by a separate battery and a separate set of wires.



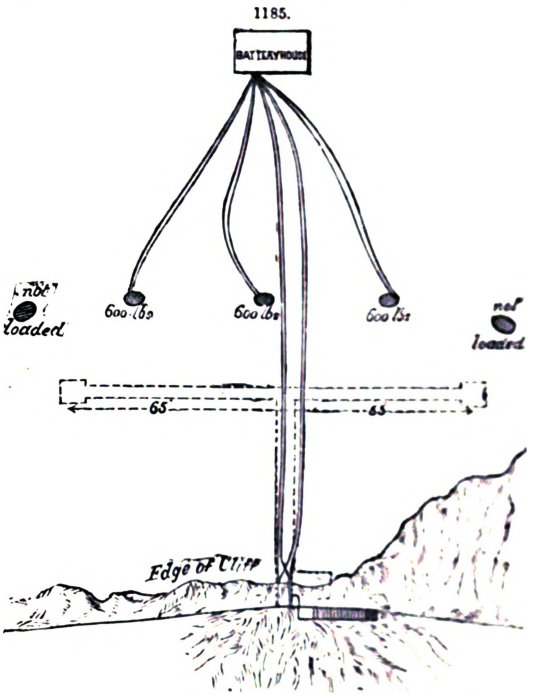

Plan of large Mines and the Galleries leading to them.

It was originally intended to have fired the five mines above by the arrangement shown in Figs. 1182, 1183. Two mercury cups situated in a convenient position, such as shown in Fig. 1183, had each to receive one wire from each mine; two main wires proceeded from these cups to the battery house, one from each cup.

The object of the cups in this case was not only to economize wire, but to prevent them from being dragged from the hands of the person who fired them.

This method was also abandoned subsequently, having the means of firing each mine by a separate battery, as will be described hereafter.

There were three voltaic batteries available for the Seaford explosion. The two principal ones were exactly similar, being both after Grove's construction.




Plan of the top of the Cliff, showing Battery House, and the situation of the three Mines above, and also the Conducting Wires leading from them, as well as the large Mine below to the Battery Shed.

Grove's consisted of five cells each, and by reference to the figures the description will be better understood, Figs. 1186 to 1188. The description need not extend further than for one cell, as the others were similar. The positive metal was zinc, and the negative platinum: two zinc plates 9 in. by 7 in., and the platinum 9 in. by 6 in. Sulphuric acid diluted in the proportion of one measure of acid to eight of water, and concentrated nitric acid, were the elements for generating the electricity. The zinc plates were amalgamated, and placed in a porcelain cell with the diluted sulphuric acid; between the two plates was inserted a cell of porous earthenware filled with nitric acid, and in this was immersed the platinum, which was attached to a bar of wood, the wood being rather thicker than the exterior breadth of the porous cell; a clamp of brass, as shown in the enlarged sketch, firmly received the two zinc plates, and secured them against the wooden bar; the connection of the zinc of one cell to the platinum of the adjacent one being made by slips of copper, as shown in Fig. 1188.

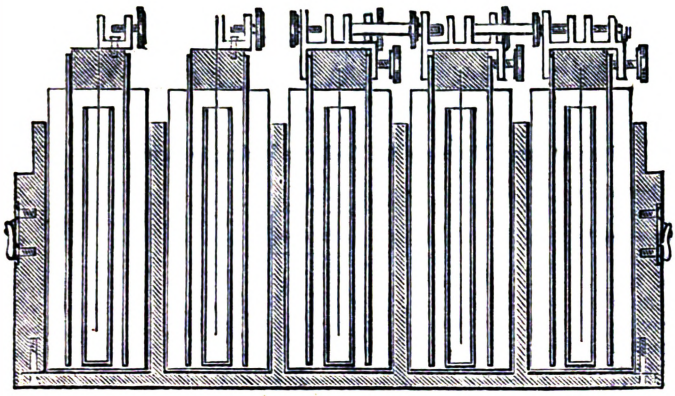
This form of battery was very convenient, as it could be charged without difficulty and be arranged for firing by two people in ten minutes; and those in the habit of using it could prepare it in six or seven minutes. It was also a very constant intensity battery, for at the end of five or six hours, which was the longest time the battery was ever kept in action here, it was in full strength. The same acid has been repeatedly used for charging the battery for a period of twenty hours, with simply adding a little water to the sulphuric acid solution, and up to that period no diminution in its strength has been discovered.

Grove's battery, of the before-mentioned size, is capable of firing one charge at a distance of 600 yds., or through a circuit of 1200 yds.; it will fire two charges simultaneously, arranging them as was originally proposed for the larger mines at Seaford, through a circuit of 1000 yds., the conducting copper wire being $\frac{1}{8}$ in. in diameter, and the platinum wire in the bursting charges $\frac{3}{8}$ in. long.

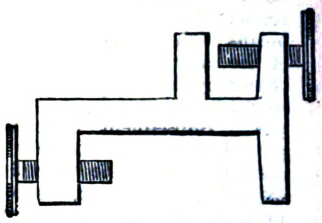
The porous earthenware cells, though they have been frequently used, are as good as at first.

The method of preserving them (as practised here) is, after the battery is taken to pieces, to soak them in a tub of water for half an hour, thus removing most of the nitric acid and metallic salt that may be in the pores, and then put them in some fresh water for an hour or so longer; the sulphate of zinc being soluble in water, is removed by this means.

1186.

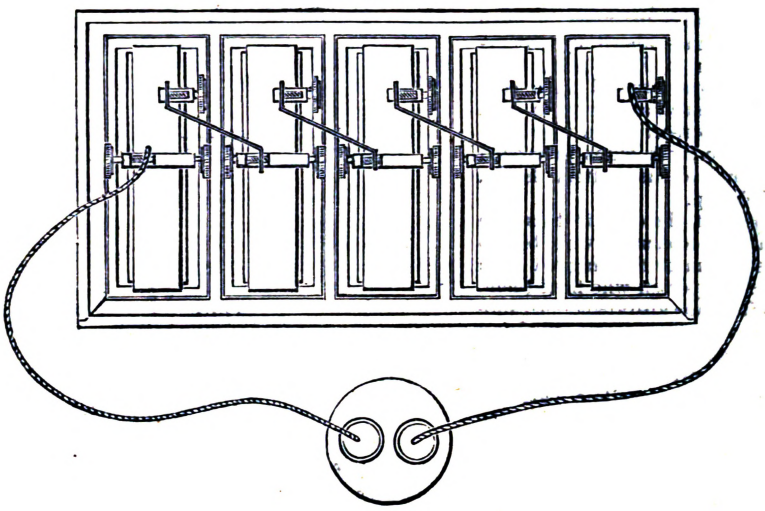


1187.



Elevation of Clamp

1188



The outer porcelain cells may be made of gutta-percha, which, however, though answering every purpose and not being fragile, would require a little care to keep them free from strong nitric acid; the dilute solution of sulphuric acid used has no effect on them.

This battery has many advantages: its connections are very simple, and easily cleaned, which are very essential points with a Grove's battery, for the nitric acid fumes will attack *brass*, *copper*, *solder*, and all such metals as are within the range of its influence. It is very constant in its power on different days, for whatever intensity it has shown on one occasion may always be confidently expected from it on another. With Daniell's battery this is not the case, the temperature having a great effect upon it, and the ox-gullet especially.

The third voltaic battery was of Smee's construction; it was in charge at Portsmouth, and, therefore, was made use of for firing one of the small mines above, as it is not generally adapted for firing charges at great distances: it will not be necessary to describe it minutely. The positive metal was zinc, amalgamated; and the negative, platinized silver; the exciting fluid was dilute sulphuric acid, one measure of acid to eight of water being generally used. It had twelve cells, and was very easily charged for use.

The conducting wire was composed of three strands of copper wire, $\frac{1}{10}$ in. in diameter, twisted as a rope, and then covered with tape, and a solution of shellac and varnish over that again. The advantage of twisting the wire thus is, that it is less liable to fracture, and is more flexible. A single strand of wire, having the same weight the yard, would convey electricity equally well, but

would soon get hard and unmanageable; it is very apt to break at bendings, and so break the circuit; twisted rope wire has a better chance, for one or even two strands may break, and the third be still left to complete the circuit. There was also used copper wire of single strand $\frac{1}{4}$ and $\frac{1}{8}$ in. in diameter.

*Bursting Charges.*—Those for the large mines below were 9 in. long, and cylinders 2 in. in diameter; and for the smaller mines about 6 in. long. They were lodged in the middle of the mine, and connected with the main conducting wire, which was brought through a piece of wood placed across the entrance of the chamber, and so jammed into it as to prevent the charges being dragged from their position.

By way of precaution, two charges were placed in each large mine, and connected with separate conducting wires, in case one pair might be damaged in tamping. The length of platinum wire for these bursting charges was different for those in each mine, one being $\frac{1}{4}$ in. long, and the other $\frac{5}{8}$ in.

It was doubtful, at the time when these charges were placed, by what method the mines would be fired. The short length of wire had been found quite sufficient for exploding charges, and it was intended to have used that if both mines had been fired by one battery; but as subsequently each mine was fired by a separate one, the bursting charges having the longer wire were attached to the main conducting wires at the mouth of the gallery, as giving a larger spark. However, either set of charges might have been used for either method with perfect success.

The twisted conducting wire, of which there were only 500 yds. available, was kept for such parts as were likely to come under the observation and close inspection of the spectators; for instance, from the battery house to the edge of the cliff, and to the top of the three shafts. That down the face of the cliff and the shafts was the single strand of thick wire before described, and covered with coarse canvas and pitch, tempered with tallow hastily made up. From the mouth of the gallery to the bursting charges below, the same thick wire was used bare, in this way:—A piece of deal, 3 in. broad, had two plough grooves run down it, in which one wire from each bursting charge of one mine was placed, and a fillet nailed over it, previously tarred. Another similar piece of deal had the other wires from these bursting charges fixed in it; these two were kept on *different* sides of the *branch*, and brought down the *main* gallery on *one* side. The same was done with the conducting wires from the other mine, which were brought down the *other* side of the main gallery, Fig. 1184.

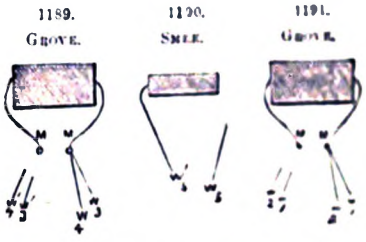
The wires proceeding from the battery house were passed over the edge of the cliff through two double blocks, that were run out on two poles. The poles were placed about 10 ft. apart, on the ground, and projected over sufficiently to enable the wires to clear the face of the cliff. One wire from each mine was run through each double block; thus the pair belonging to each mine were kept 10 ft. apart down the face to the entrance gallery, where they were attached by soldering to those from their respective bursting charges: previous to soldering on these wires to those leading to the mines, the continuity of the circuit was tested by a galvanometer; and as every one was complete, the charge having $\frac{5}{8}$ in. platinum wire was selected for the purpose of firing. One Grove's battery was devoted to each large mine.

The three small mines above, each charged with 600 lbs. of powder, had each a battery to fire them, the two extreme ones by the two Grove's, and the centre one by the Smee's already alluded to. The wires were brought from the shafts into the battery house. The arrangement for firing was made as sketched in Figs. 1189 to 1191. M, M, M, M, are mercury cups into which the poles of the Grove's battery were plunged.

The operators stood with their backs to the cliff, facing their respective batteries, the mercury cups being between them and the batteries.

$W_1$ and $W_2$ represent two wires, one proceeding from one large mine below, and the small one above on that side. $W_3$ and $W_4$ represent two others, one proceeding from the other large mine below, and the small one on the side above. $W_5$ represents the wire from the centre mine above.

$W_1'$, $W_2'$, $W_3'$, $W_4'$, $W_5'$, are those corresponding to $W_1$, $W_2$, $W_3$, $W_4$, $W_5$, that is, leading to the same mines.




The orders for firing the mines were to explode the large ones first, and when it was known that they had gone off, the three small ones were to be fired. On the word to make ready, $W_1$, $W_2$, $W_3$, $W_4$, were inserted in their respective mercury cups, as shown in Figs. 1189 to 1191; and $W_5$ was attached to the binding-screw of one terminal pole of the Smee's battery.

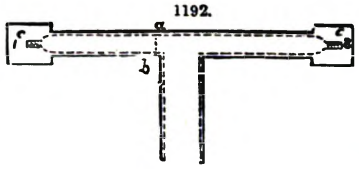
$W_1'$, $W_2'$, were held by the officer in charge of that battery, one wire in each hand. $W_3'$, $W_4'$, were similarly held by the officer over that battery, and $W_5$ was in Lieut. Crossman's charge.

Captain Frome arranged to give the signal thus:—"One, two, three, *fire*," and "One, two, three, *fire*;" the first fire referring to the large mines (when the wires leading to those were to be plunged into the other mercury cups), and the second fire to the three small mines (when all three officers had to complete the circuits corresponding to those). At the first word fire, the two large mines exploded, and the effect produced separated the cliff behind the three smaller mines so quickly as to drag all the remaining wires out of the window, thus preventing the upper ones from being fired. The wire $W_5$, attached to the binding-screw of Smee's battery, pulled it over, and the shock made the other batteries jump on the table, mixing and spilling the acids.

With respect to the plan originally proposed for firing the mines below, namely, by one battery, and placing the charges in one continuous circuit, it was asserted to be an uncertain method; because, if one platina wire was a little shorter than the other, the short one would fire first, and, thus disconnecting the circuit, would prevent the other from exploding.

Subsequent experiments (as has been before stated) have proved this opinion erroneous, for in all trials that have been made at Portsmouth of that method of firing, the length of platina wire was always judged by the eye, *never* accurately measured. But a safe means could have been adopted to prevent even this contingency, and have placed beyond possibility the chance of only one charge exploding. The diagram. Fig. 1192, will explain it.

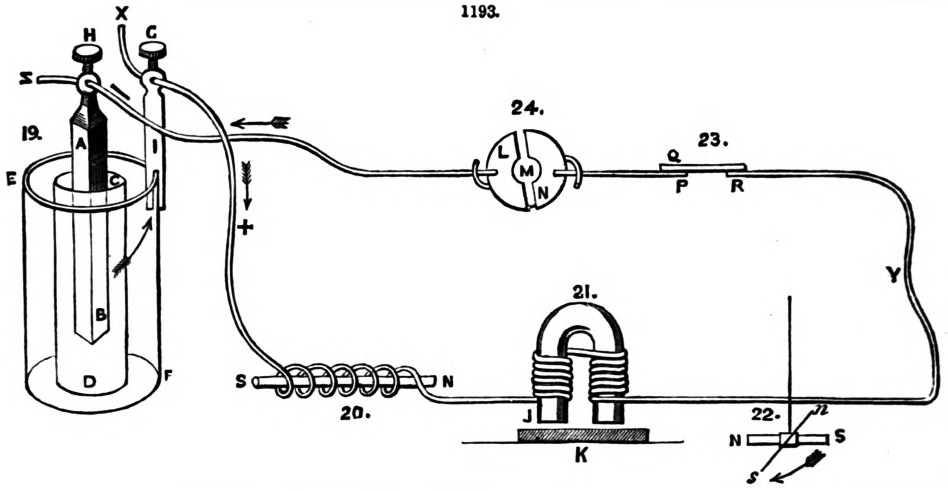
1192.




The dotted lines represent the copper conducting wires leading to charges $C_1$ and $C_2$. The length of platinum wire in $C_1$ may be made $\frac{3}{8}$ in. long, that in $C_2$ $\frac{5}{8}$ in.; and at points *a* and *b* connect copper wires of the same thickness as the conducting wires, leading towards each other, but not approaching nearer than 1 in., and this interval connected by soldering on a platina wire 1 in. long, between the two, and encasing it in wood to protect it from possible fracture in the tamping, and securing it from all strain. On completeing the circuit at the battery, $C_1$ would fuse before $C_2$, being $\frac{1}{4}$ in. shorter, but the electric circuit through $C_2$ would still be complete by the aid of the connections *a b*; similarly, $C_2$ must fuse before the platina wire at *a b*, being shorter by $\frac{1}{8}$ of an in.; and the interval between the explosion of $C_1$ and $C_2$ would not be more than $\frac{1}{4}$ of a second at the most; indeed, practically instantaneous.

*Application of Permanent Magnets to the Explosion of Mines and Submarine Charges.*—Electro-magnetism and magneto-electricity may be explained and illustrated as follows: A cell of Daniell's battery is represented in Fig. 1193; a rod of zinc A B is placed within a tube C D of porous earthen-

1193.

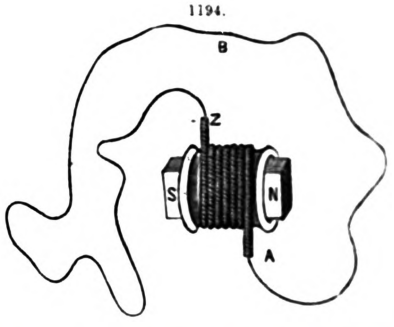



ware, the vessel E F being of copper. The porous tube C D, containing the zinc rod A B, is filled with a mixture of one part sulphuric acid and ten parts water; the space between the earthenware tube and the copper cell E F is filled with a saturated solution of sulphate of copper; this saturated solution is prepared by pouring boiling water on a superabundance of crystals of sulphate of copper and stirring them; to this solution one-tenth acid should be added. A binding-screw H establishes metallic contact between the zinc rod A B and one end of a wire, the metals being clean at the points of contact; the other end of the wire is brought into metallic contact with the copper cell E F by means of the binding-screw G and the metal support I, which may be either of brass or copper.

In the coil of insulated copper wire at 20, when the positive galvanic current descends and passes in a right-handed spiral round the soft iron bar N S, 20, the iron bar becomes an electro-magnet, the north pole N on the right of the observer. The bar of soft iron N S loses its magnetism or becomes demagnetized the instant the continuous metallic circuit X, 20, 21, V, M Z is broken. Suppose the wire to be made fast to two metal discs L and N, 24, which do not touch, then the galvanic current will not circulate as the continuous metallic contact is broken; but the instant a plug of metal, touching both the discs, is placed in the hole M, the galvanic current circulates, and S N, 20, will be found to acquire a considerable quantity of magnetism, the cell 19 being charged and arranged as before directed. But as soon as the plug M is withdrawn, or the metal bar Q, 23, removed, the circuit is broken, and the bar S N, 20, loses its magnetism. The bar Q, 23, establishes metallic contact between the ends P, R, of the wire. *It must be observed by those who are not acquainted with galvanic electricity and technical terms that positive electricity passes from the lower part of the zinc rod through the fluids and porous pot* C D, *to the copper cover* E F, *and then continues its course* X, +, 20, 21, 22, V, 23, *the plug* M, *and returns to the upper end* H *of the zinc bar.* The electric current passes from the *zinc* to the *copper* through the porous pot and fluids, and leaves the battery by the wire (which may be of immense length) attached to the copper, passing through any apparatus that maintains continuous metallic contact, and returning to the battery by the wire attached to the end of the zinc which is not immersed in the fluid; the copper, although the negative metal, forms in this case the *positive end* (+) of the battery; and the zinc, although the positive metal, forms the *negative end* (−). A piece of soft iron, 21, when bent in

the form of a horse-shoe, round the horns of which is wound spirally a length of well-insulated copper wire, acquires a considerable quantity of magnetism while a galvanic current is passing through the wire; one end of the magnet so arranged becomes the north pole and the other the south, if the spiral be wound in the same direction throughout, supposing the horse-shoe to be unbent and made straight. When a galvanic current circulates round the horns of a horse-shoe electro-magnet 21, a piece of soft iron K, near its ends or poles, will be raised; but as soon as the plug of metal M, which is technically termed a contact-peg, is removed, the electro-magnet 21 becomes demagnetized, and K is disengaged or allowed to fall. Electro-magnets of the form 21 have been arranged so that they sustained a weight nearly equal to a ton. If a positive galvanic current passes along a wire in the neighbourhood of a magnetic needle N S, 22, the needle will be deflected, and will take a position *n s*, Fig. 1193, at nearly right angles to the wire. But when the circuit is broken by withdrawing the contact-peg M, or by removing the strip of metal S, 23, the magnetic needle will return to its original position N S. The Danish philosopher Oersted, about the year 1820, discovered the connection between galvanism and magnetism; he also illustrated his discovery by many phenomenal developments. In applying electro-magnetism to the business of telegraphy, the next important discovery was made by Steinheil, who found that the earth might be used to make up half the circuit of a galvanic current; for if a number of cells like 19 be combined, so that the battery may be of sufficient strength, the discs of metal M, N, 24, Fig. 1193, may be buried in the earth at a great distance apart, and yet the circuit will be complete although the return wire is dispensed with. Faraday found by experiment that the converse phenomena also takes place, namely, that on inserting a permanent magnet N S, Fig. 1194, into the middle of a helix of insulated wire A Z, a current of electricity is generated in the circuit of wire A B Z; the direction of the current depending upon the pole inserted and the end of the spiral with respect to the direction of its windings.

1194.

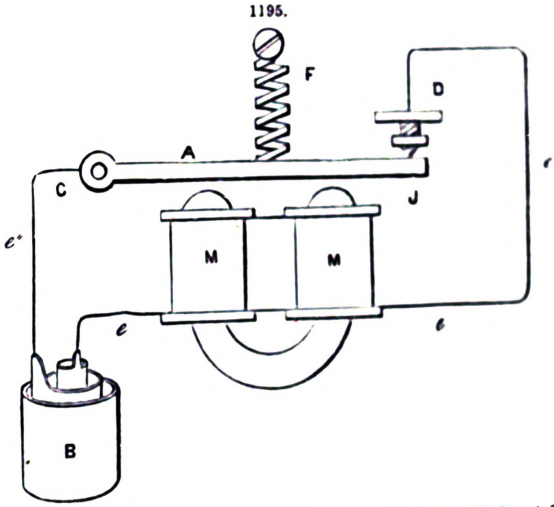



This experiment of Faraday has been much overrated, for, when Oërsted had discovered that an electric current produced a magnet, it required but little analytical skill to observe that the converse phenomena takes place, namely, that a magnet would produce an electric current.

Many vague conjectures and absurd theories were entertained about the mechanical action of the galvanic and electro-magnetic currents until Ohm, a German physicist, proved that $I = \frac{F}{W}$, in which F = the electric motive force, W = the resistance, and I = the intensity. Faraday proved experimentally that $Q = s\,I$, Q being the quantity of electricity conveyed by the current, I the intensity, and $s$ = the time during which the current circulates. Dr. Joule asserts, following out the ideas of Dr. Mayer, that $U = I^2\,W\,s$; in which U = units of work. However, the proofs by which our present mechanical equivalent of heat has been established are far from being satisfactory. This experimental proposition of Mayer and its converse may or may not be true. The proofs given by Professor Tyndall and Dr. Joule are not conclusive. Many forms of battery, a variety of mechanical contrivances, and numerous formulæ, have been employed in the business of telegraphy, the most useful of which we give elsewhere, in order of merit. But those developments, except the local battery of Morse, are of a very second-rate character compared with those we have enumerated.

To illustrate what we have stated with respect to the electro-magnet, we will explain the simple principle upon which W. Siemens constructed one of his first telegraphs. Suppose A J, Fig. 1195, to be a piece of soft iron, supported on an axis C at one end, and lifted by a spring F in the middle, so as to press A J upwards against the metallic contact-screw D. Let the positive pole of the battery B be connected by a wire *e* with one end of the wire-coil of an electro-magnet M M, the other end of the coil being connected with the contact-screw D, by a wire *e'*; while a third wire *e''* completes the circuit; *e''* connects the negative pole of the battery with C the axis of the piece of soft iron or armature A J. When the circuit is complete, the current circulates in the coils of the electro-magnet M M, magnetizes them, and causes the soft iron lever A J to be attracted to the poles; this operation breaks the metallic contact between the lever C J and the contact-pin D. When this occurs, the galvanic current ceases to circulate in the coils of M M, the soft iron cores of which become demagnetized, and have no longer the power to retain C J which is therefore lifted by the spring F. But then contact is again established between D and

1195.



C J, and the galvanic circuit again completed. So that when the apparatus is properly adjusted, the soft iron lever A J will continue to move up and down as long as the battery and the mechanical arrangement remain in working order. One galvanic circuit may be arranged to give motion to two or more such levers as A J at the same time, which motions may be applied to move pointers on dial-plates and convey telegraphic messages.

*Magnetism*, or the property of permanent polarity, was formerly supposed to belong to iron only. Later researches show that this is to be shared, though not equally, with nickel, cobalt, and chromium. Occasional magnetism may be excited in most substances, as is shown by their influencing the oscillations of a freely-suspended magnetic needle. But this influence is much weaker in all other substances than in the four which we have named. *Silver*, which stands the highest of all the other metals, is nine times feebler in this respect than iron; *gold* fifteen times, and marble nearly twenty times more weak. Iron acquires magnetism by contact or suitable friction with a magnet, by being suitably rubbed or struck in a proper position, by exposure to refracted light of the sun, and even by being left to stand in a nearly vertical position. Here it is enough to say that, owing to the ease with which it is accidentally developed, it is extremely difficult to find in the shop of a philosophical instrument maker, for instance, a tool or strip of iron which is not in some degree magnetic. In all its conditions and states it is susceptible of this property, but develops it differently in each. Thus, grey crude iron becomes sooner and more intensely magnetic than white iron, but yields in both these regards to wrought iron and steel. Soft ductile iron is more easily and more strongly magnetizable than steel, but does not retain its magnetism as well. A similar relation is observable between untempered and tempered steel. The magnetism of iron may be weakened or lost by methods similar to those which originally impressed it. The filings of a magnet are less magnetic than the solid mass. A heavy sudden blow or shock against a hard body will sometimes destroy magnetism. Heat always diminishes it; although there are some peculiarities which have been observed in this regard that are difficult of explanation. It undergoes deterioration whenever similar poles of two equally strong magnets are kept in prolonged contact; and, finally, is always abated by alloying with other substances, and may be destroyed entirely by increasing the proportion of alloy. Arsenic is, in this respect, the most active of the metals, though an alloy of two-thirds arsenic does not entirely prevent the mass from being attracted by the needle. Mushet, however, affirms that 22 per cent. of manganese effectually destroys magnetism in an alloy of iron. Malleable iron is an excellent conductor of *electricity*; and although in this respect inferior to copper and zinc among the easily oxidized metals, and to gold, silver, and platinum among the others, it is yet, for economy, universally employed for telegraphic purposes and for lightning-rods. In the voltaic pile it follows zinc in the order of electro-positive metals. The *electro-magnetic* properties of iron are very remarkable, in the facility with which it is converted into a magnet of great energy during the passage through it of a galvanic or electric current. It is on this that the electro-magnetic telegraph owes, in part, its adaptation and success.

The ignition of gunpowder by the direct magneto-electric current, though well known to be practicable, had, in 1861, never been applied to military or industrial operations in England, and no satisfactory experiments showing its practical applicability to these purposes had been published.

In the first experiments of Abel and Wheatstone a powerful magneto-electric machine constructed by Henley was used.

A few trials sufficed to show that, even with this instrument, gunpowder itself could not be ignited with any degree of certainty. Results obtained with Statham's and other fuzes, though superior to those furnished by gunpowder alone, were still far from satisfactory.

The first experiments were, therefore, directed to the discovery of a suitable agent to serve as a perfectly certain medium or priming material for effecting the ignition of charges by means of the magneto-electric machine. For this purpose a variety of compositions of a more or less sensitive character were prepared for trial with the magnet.

Many of these compositions furnished results to a certain extent favourable; a number of fuzes, primed with them, having been fired in succession with the magnet, and from two to four charges in one circuit having been ignited in a very few instances. But no perfect certainty of discharge was attained with any one of the materials, the attempt to fire a fuze being frequently unsuccessful; while no difference between it and a successful fuze containing the same composition could be detected by careful examination.

These preliminary trials, however, established the fact that the sensitiveness or ready explosiveness, of a priming material was not alone sufficient to determine its success, but that those which possessed a certain, though not too considerable, degree of conducting power, were more readily and certainly ignited than others of a far more sensitive character.

Some successful results obtained accidentally with one of the experimental compositions, which had become damp by exposure to the air, led to a trial of the effect of moisture in promoting the ignition of but slightly sensitive compositions; and it was ultimately found that the impregnation of ordinary gunpowder with a small amount of moisture, by an expedient similar in principle to one adopted with considerable success by Capt. H. Scott, in connection with charges to be fired by the induction-coil machine, rendered its ignition by means of the magnet a matter of certainty.

Some important precautions were, however, indispensable to the attainment of this definite result. If the slightly damp powder were employed in a finely divided condition, it very frequently became caked between the wire terminals in the fuze, and the current would then pass through the composition without igniting it. This was found to take place occasionally, even when the powder was employed in its original granular condition. Several attempts were made to overcome this difficulty by modifying the form and position of the terminals; and an arrangement of a completely successful nature was eventually contrived, in which only the sectional surfaces of the extremities of the terminals, which consisted of fine copper wire, $\frac{1}{40}$ in. diameter, were exposed in the interior of the fuze so as not to project at all. The prepared gunpowder, therefore, simply

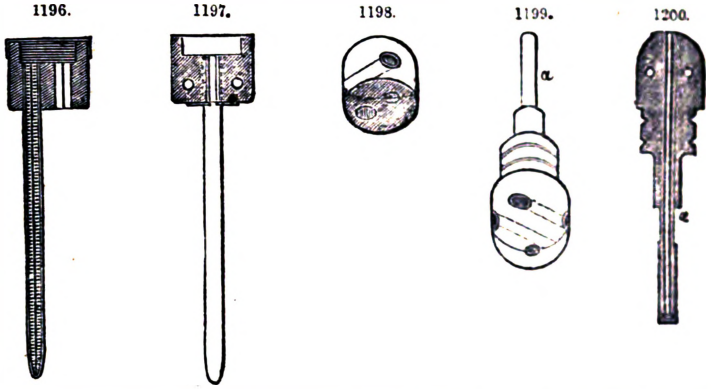
rested upon the surfaces, and a perfect uniformity in the action of the fuze was attained. The priming composition consisted of fine-grain gunpowder, which had been soaked in an alcoholic solution of chloride of calcium, of a strength sufficient to impregnate the grains with from 1 to 2 per cent. of that salt. The prepared powder was exposed to the air for a short time, to permit of a sufficient absorption of moisture by the deliquescent salt.

Upwards of 500 quill fuzes, of the description employed for firing guns, primed with the prepared gunpowder and fitted with the arrangement of the terminals above referred to, were fired with the large lever-magnet. The failures did not amount to more than 3 per cent., and were all proved to be due to defective manufacture.

This fuze was found to be easy of manufacture and permanently effective. While, however, it presented a certain means of effecting the ignition, by the aid of a powerful magnet, of single charges, or of a large number to be fired in moderately rapid succession, it was inapplicable to the ignition, with certainty, of more than one charge in circuit.

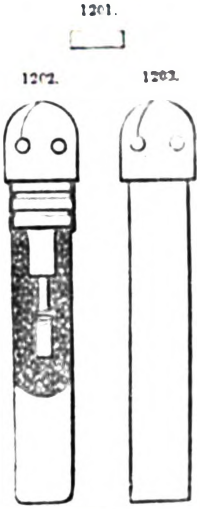
A new description of priming material for the fuze was prepared soon afterwards, which greatly exceeded in sensitiveness any of the other compositions hitherto tried. A very gradual separation of the armature from the large magnet sufficed to effect the ignition of the fuzes primed with this material, and the induced current obtained by means of a very small magnet, with a rotatory armature, such as that employed in Wheatstone's magneto-electric telegraph, was sufficiently powerful to produce the same result.

The fuze-head, which is of box-wood, contains three perforations, Figs. 1196 to 1198; the one passing downwards through the centre receives about 2 in. of double insulated wire *a a*, Figs 1199, 1200, two copper wires of 24-gauge, 0·022 in. diameter, enclosed side by side, at a distance of




$\frac{1}{16}$ in., in a coating of gutta-percha of $\frac{1}{8}$ in. diameter; the other two perforations, which are parallel to each other on each side of the central one, and at right angles to it, serve for the reception of the circuit wires. The arrangement for securing the connection of these with the insulated wires in the fuzes is as follows: —

The piece of double covered wire above referred to is originally of a sufficient length to allow of the gutta-percha being removed from about $1\frac{1}{2}$ in. of the wires. These bare ends of the fine wires, which are made to protrude from the top of the fuze-head, are then pressed into slight grooves in the wood, provided for their protection, and the extremity of each is passed into one of the horizontal perforations in the head, in which position it is afterwards fixed by the introduction into the hole of a tightly-fitting piece of copper tube, so that the wire is firmly wedged between the wood and the exterior of this tube, and is thus at the same time brought into close contact with a comparatively large surface of metal. It will be seen that it is only necessary to fix one of the circuit wires into each of these tubes, in the opposite sides of the fuze-head, in order to ensure a sufficient and perfectly distinct connection of each one of them with one of the insulated wires in the fuze.




The extremity of the double covered wire, which protrudes to a distance of about $\frac{3}{4}$ of an in. from the bottom of the fuze-head, is provided with a clean sectional surface by being cut with a pair of sharp scissors, care being taken that the extremities of the fine copper wires are not pressed into contact by this operation.

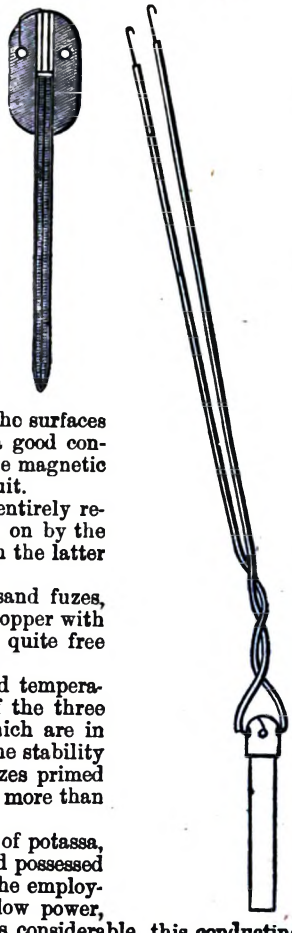
A small cap of about $\frac{1}{2}$ an in. in length is then constructed of thick tin-foil, Figs. 1199, 1201, into which is dropped about 1 grain of the priming material. The double wire is then inserted, and pressed firmly down into the cap, so that the explosive mixture is slightly compressed and in close contact with the surfaces of the wire terminals.

The cap is fixed by winding a piece of twine once or twice round its upper part, tightening the ends of this, and then removing it. The actual fuze is then ready for enclosure in a small charge of gunpowder, Figs. 1202, 1203. The powder is contained in a paper case tied on to the head, or in a cylinder of sheet tin, tightly fitting on the fuze-head at one end; the other, after the introduction of the powder, being closed with a plug of clay or plaster of Paris.

It is advisable to have the fuzes ready fitted with pieces of insulated wire about 2 ft.

in length, twisted together as shown in Fig. 1205. The ends of the wires, after they are passed through the connecting holes in the fuze-head, should be tightly fixed in their position by the introduction of a short piece of copper wire

1204. 1205.



The phosphide of copper fuze for firing cannon, Fig. 1204, differs slightly in its construction from the mining fuze. The fuze-head is longer than in the latter, and of such a form that the double covered wires, which are fitted into it in the manner already described, are completely enclosed in it, the lower extremity of its central perforation still remaining free to receive the top of the quill or copper tube charged with powder, like the ordinary tube arrangement for firing cannon.

The priming material contained in the fuze is prepared by reducing separately to the finest possible state of division the sub-phosphide of copper, sub-sulphide of copper, and chlorate of potassa, and then mixing these powdered substances very intimately, in the proportions of 10 parts of the first, 45 of the second, and 15 parts of the third, by rubbing them well together in a mortar, with the addition of sufficient alcohol to thoroughly moisten the mass. The mixture is afterwards carefully dried, and may be safely preserved in closed vessels until required.

In the experiments subsequently carried on with fuzes which contained this composition, it was found that a slight residue, consisting principally of the coke employed, occasionally remained on the surfaces of the terminals in the fuze after its discharge, and, by forming a good conducting link between them, interfered with any further effects of the magnetic current in other directions, by the establishment of a complete circuit.

The obstacle to the complete success of the composition was entirely removed by the substitution of another material, more easily acted on by the chlorate of potassa than the coke, and answering equally well with the latter as a conducting medium, namely, the sub-sulphide of copper.

No instance has occurred in the discharge of several thousand fuzes, primed with the mixture of sub-phosphide and sub-sulphide of copper with chlorate of potassa, in which the terminals have not been found quite free from adherent residue after the ignition.

The sub-phosphide of copper, which is produced at an elevated temperature, is a compound of very stable character, and the mixture of the three constituents is quite as unalterable as the explosive mixtures which are in general use for the preparation of percussion caps, and so on. The stability of the mixture has been submitted to very satisfactory tests. Fuzes primed with it have lost none of their delicacy and certainty when tried more than two years after preparation. See ATOMIC WEIGHTS, p. 195.

The sub-phosphide of copper, intimately blended with chlorate of potassa, forms a mixture in a high degree sensitive to the effect of heat, and possessed at the same time of some power of conducting electricity. With the employment, however, of magneto-electric machines of comparatively low power, and in cases where the resistance to be overcome by the current is considerable, this conducting property is not sufficient to ensure the ignition of the mixture by assisting the passage of the current across the interruption in the metallic circuit—across the small distance between the terminals of the wires in the fuze. It must be borne in mind that the striking distance, or the space between the terminals, across which the current from even a powerful magneto-electric machine will leap, is very small. With the large lever-magnet the spark could only be produced when the wires were almost in contact. Since, however, it is indispensable to the proper insulation of the wires in the fuze arrangement that the terminals should be at least $\frac{1}{16}$ of an in. apart, it will be readily understood how essential to success in operations with these machines it is that the priming material should possess considerable conducting power. Hence the necessity of increasing the conducting power of the mixture of sub-phosphide of copper and chlorate of potassa; a result which it has been already stated was attained in the first instance by the employment of finely powdered coke, and afterwards by the substitution of sub-sulphide of copper for that substance.

Many experiments were of course required to determine the proportions in which it was advisable to employ the conducting constituent, so as to facilitate the passage of the current through the mass as far as possible, without interfering too much with the sensitiveness of the explosive mixture, or producing an almost perfectly continuous connection between the two poles in the fuze, and thus promoting the passage of the current so greatly as to prevent the ignition of the composition.

Considerable difficulties were encountered in the endeavours properly to balance these conditions, when attempts were made, which will presently be mentioned, to apply the mixture in question to the ignition of several charges in circuit. The increase in the resistance of the current, consequent on the introduction of more than one interruption in the metallic circuit, necessitated an increase in the conducting power of the mixture, which it was difficult to attain, unless at a considerable sacrifice of the sensitiveness of the composition.

It was consequently found that when the proper conditions had been attained for ensuring the passage of the current through several—five or six—fuzes in circuit, the absolute certainty of the fuze, when applied in this manner, had been sacrificed. Thus, out of several fuzes tried together, which had been most carefully prepared, so as to be as far as possible perfectly alike, the current would ignite a few, passing through the others without affecting them, and would thus point to

minute differences in the conducting powers and sensitiveness of different portions of one and the same quantity of the mixture, which was prepared in such a way as to ensure the greatest possible uniformity.

The results of many experiments established the fact, that the proportions of ingredients already referred to furnished a mixture possessed of the highest conducting power attainable without detriment to the sensitiveness or ready explosiveness of the material. The certainty of its action, when applied in the fuze, to the explosion of a single charge, by employing a permanent magnet instead of a battery to establish the current, has been proved by the ignition of several fuzes, without failure. See Figs. 1193, 1194.

Experiments, made with the aid of this composition, established the fact that the current obtained by means even of a very powerful permanent magnet, when applied to the ignition of several charges arranged in succession in one circuit, is very limited in its powers. In illustration of this it may be stated that, on trial being made of twenty-one consecutive sets of four charges, eighteen of the sets were perfectly discharged; but, in the other three sets, only two or three of the charges were ignited. Out of five sets, of five charges each, only two sets were completely discharged; and in several attempts made to ignite six fuzes in one circuit, only four were fired in each case. In all these experiments, when charges had escaped ignition, the current had passed through the sensitive composition without firing it. When the discharged fuzes were removed, and the remaining ones properly connected, they were all fired.

It has been already stated that no beneficial effects were attained by modifying the proportions or ingredients in the priming composition, so as to diminish or increase its conducting power.

Three charges were therefore the most that could be ignited *with certainty* by means of a powerful electro-magnetic machine, when they were arranged in succession in simple circuit.

The plan, originally suggested by M. Savare, of arranging the charges in divided circuits, was next tried, and furnished far more successful results. The simultaneous ignition of twenty-five charges was repeatedly effected by means of the large magnet, each charge being connected with a separate branch attached to the main line, which led from one pole of the magnet, and their connection with the earth established by means of uncovered copper wire, the extremity of which was wound round an iron stake driven into the ground.

A still larger number of charges (forty) was similarly exploded on several occasions.

These results were all obtained with the large magnet, the current being established by rapidly separating the armature from the poles by means of a lever. By a simple arrangement for shifting the connection of the main wire with the exploded charges, from them to a second series, similarly arranged, twenty-five were also simultaneously ignited, on allowing the armature to return to the poles of the magnet. It was found, moreover, that the same number could be fired by means of this magnet, even if two folds of thick brown paper were interposed between the poles and the armature, so that on depression of the lever the armature had no longer to be forcibly detached, but simply to be removed from the magnet.

These successful results led to trials of magneto-electric machines of comparatively small size, with revolving armatures. In the employment of these machines, it was of course not expected that any single induced current obtained from them should distribute itself among a number of fuzes placed in divided circuit, as was the case with the comparatively much more powerful current obtained with the large magnet; but it was hoped that the very rapid succession of currents furnished by them would produce a very similar result, by distributing themselves over the different branches of the circuit with which the fuzes were connected, and that the ignition of the whole of the fuzes, though it could not be so positively instantaneous as when the one current was discharging the entire number, might yet be effected with such rapidity as practically to amount to a simultaneous discharge.

The results obtained fully confirm these expectations. With a small horse-shoe magnet, 7 in. in length, 1 in. in breadth, and 1¾ in. in thickness, provided with a revolving armature and multiplying wheels, by which great rapidity of motion could be attained, twenty-five charges were fired; the effect of the discharge on the ear was, however, not like that of one single explosion, as was the case in the former experiments, but like that of an exceedingly rapid volley, in which the explosion of any single charge could not be distinguished.

Still more favourable results were obtained with a very compact arrangement of six magnets, each about half the size of the above, devised by C. Wheatstone, for the production of an extremely rapid succession of currents, established in such a manner that the effect would be almost equal to a continuous current.

It consisted of six small magnets, to the poles of which were fixed soft iron bars surrounded by coils of insulated wire. The coils of all the magnets were united together, so as to form, with the external conducting wire and the earth, a single circuit. An axis carried six soft iron armatures in succession before each of the coils. By this arrangement two advantages were gained; all the magnets simultaneously charged the wire, and produced the effect of a single magnet of more than six times the dimensions, and at the same time six shocks or currents were generated during a single revolution of the axis, so that, when aided by a multiplying motion applied to the axis, a very rapid succession of powerful currents was produced. A single large magnet with a rotating armature could not be made to produce the same succession of currents without the application of considerable mechanical power. Another peculiarity of this apparatus was that the coils were stationary, and the soft armatures alone were in motion; by this disposition the circuit during the action of the machine was never broken. In the usual magneto-electric machines with rotating armatures the circuit is necessarily broken twice during every revolution, and this frequently gives rise to irregularities in the production of the currents. By the construction adopted, the currents can never fail to traverse the circuit. It must be borne in mind that our account of this investigation is taken, with some alterations, from an inflated report to the Secretary of State for War,

by Wheatstone and Abel. Such documents are generally cooked up. See 'Professional Papers of the C.R.E.,' vol. x.

The total weight of the instrument, enclosed in a case, was 32 lbs. 11 oz. It was enclosed for transport in a small packing-case, weighing about 7 lbs.

The system of firing charges by means of magneto-electricity, with the aid of the phosphide of copper fuze, having been thus far successfully developed, a series of experiments was instituted on it at Chatham, for the purpose of thoroughly testing its certainty and applicability in the field, and subsequently for ascertaining the extent to which it admitted of application to the explosion of submarine charges. These experiments extended over a period of six months, and were performed under various conditions of weather.

The magnetic apparatus employed in all the field experiments was so arranged that the whole apparatus was enclosed in a box, the only exposed portions being the binding-screws for the attachment of the wires, a handle for setting the armatures in motion, and a key, by the depression of which, at a given signal, the circuit could be completed.

To employ the instrument at any moment, the following were the operations necessary:—

The insulated wire and the copper wire passing to the earth (the earth taking the place of the return wire) were fixed to the apparatus by means of the binding-screws; the instrument was raised from the ground by being placed on its packing-case; at that height a man could operate with it when in the kneeling posture.

At a signal ready, the handle was turned with one hand, so as to cause the armatures to revolve with the greatest possible velocity whilst the other hand was pressed against one corner of the instrument, close to the key, so as to steady the box, and to be ready at the signal fire to depress the key with the thumb.

The connection of the instrument with the earth was effected as follows:—

A moderately clean spade was selected from among those used by the men in digging holes for the charges. One end of a piece of stout copper wire was placed under the edge of the spade, in such a manner that when the latter was firmly forced into the ground it was pressed by the earth on both sides against the iron surface. The protruding wire was wound once or twice round the bottom of the spade-handle, and then attached to the binding-screw of the permanent magnet.

The gutta-percha-covered wire used in the experiments having been in occasional service at Chatham for some years, the coating had sustained some injury in two or three places. Such defects were protected from possible contact with the earth by means of waterproof cloth or sheet india-rubber. The total length of wire used was 881 yds., of which 600 were extended, lying along the ground.

To the extremity of the covered wire a number (from 12 to 25) of pieces of similar insulated wire, varying in length between 3 and 6 yds., and serving to connect it with the individual charges, were attached in the following manner:—About 6 in. of the extremity of the main wire and of each of the branch wires were laid bare, and cleansed; the end of the former was then surrounded with those of the latter, placed in an opposite direction, and the whole tightly twisted together by means of pliers, so as to be brought thoroughly into metallic contact with each other and with the main wire. The twisted wires were then bound round with moderately fine copper wire, which was made to bring every portion of the exterior of the bundle into connection. The joint was made rigid with pieces of stick tied against it, and the whole securely enveloped in a piece of waterproof cloth or canvas, to protect it from damp and contact with the earth.

These connections, though of a very rough description, and most readily prepared by any soldier, were thoroughly effectual. No instance occurred in the whole of the experiments of the failure of a charge which could be attributed to an imperfect metallic connection of its branch wire with the main wire.

The following was the method adopted for connecting the fuzes with their respective branch wires and with the earth:—

The fuzes, as they were manufactured, were always fitted, as shown in Fig. 1205, with two pieces of covered wire twisted together. They were thus ready for insertion into the bag or other receptacle containing the charge of gunpowder, the ends of the covered wires protruding from the opening of the latter to a convenient distance for effecting the junction with the branch and earth wires, so that a complete galvanic circuit might be established, which was excited by the permanent magnet. The extremities of one of the other fuze-wires and of a branch wire, from both of which the gutta-percha was removed to a distance of about 2 in., were connected by hooking them firmly one in the other with pliers, in the manner shown in Fig. 1206. A piece of fine copper

1206.

binding wire, about 6 or 8 in. in length, was then twisted over the whole of the connection, and the joint was finally enclosed in a small wrapping of oiled canvas, in a manner similar to that adopted at the principal junction with the main wire.

The extremity of the other fuze-wire was attached to an uncovered copper wire of sufficient length to bring the whole of the charges into connection with each other in this manner. The wire was fixed in a convenient position by being twisted round short stakes or pickets driven into the ground, and its extremities were buried in the earth, being attached either to spades, as already described, or to zinc plates about 8 in. square.

With reference to the earth-connection, the employment of large metallic surfaces was also proved, by repeated experiments at Chatham and Woolwich, to be superfluous. The simple insertion into the ground of the uncovered extremities of the fuze-wires was found to afford a perfectly sufficient connection for ensuring the ignition of the charges.

The largest number of charges which it was attempted to fire at once at Chatham was twenty-five. The ignition of twelve charges was repeatedly effected, and with such rapidity as to have the practical effect of a simultaneous discharge of the whole. With twenty-five charges the interval between the first and last discharge was very decided, being certainly longer than when the same number of charges were fired at Woolwich with the employment of a greater length of wire, of which, however, the larger portion was coiled up, the space between the earth-connections being only about one-half of that introduced at Chatham; yet it was considered that even the ignition of the twenty-five charges, at a distance of 600 yds. from the magnet, and with the employment of 881 yds. of covered wire, and, in addition, about 100 yds. in the form of branch wires, was effected with sufficient rapidity to allow of that number being employed in cases where a simultaneous discharge was required.

Another instance of the apparent effect of increased resistance, in the form of an increase in the length of wire laid out, in diminishing the rapidity of discharge, was observed in the employment of one branch wire of four or five times the length of the others. A distinct interval was noted between the explosion of the other eleven charges and that of the one attached to the longer branch wire.

Experiments were made to ascertain whether, to complete the circuit, the employment of a second insulated wire, in the place of 600 yds. of earth-connection, would modify the rapidity of ignition of a number of charges, but no difference of effect was observed.

It need scarcely be stated that, in dealing with electricity produced by a permanent magnet, defects in the insulation of the main and branch wires had to be very carefully guarded against. Several failures in the first experiments were eventually traced to some defect of that kind. An instance even occurred, before the proper method of protecting the connections of the charges with the insulated wires was adopted, in which the deposition of moisture upon the gutta-percha-covered wire, near the charge, prevented the ignition of the latter, by forming a connecting link between the extremity of this wire, where it was exposed and attached to the fuze, and the uncovered wire leading to the earth, in consequence of the two wires being in contact at a distance of several inches from the fuze.

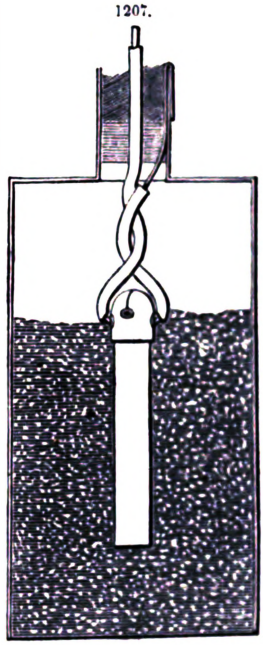
It is therefore always a preliminary precaution of primary importance that the insulating covering of the wire to be employed be carefully inspected while the latter is being laid out for use, and that any imperfections be protected from possible contact with the earth or from the access of moisture, a result readily attainable by the application of some waterproof envelope to the injured portion.

The experiments instituted at Chatham with the object of applying the current produced by a permanent magnet to the ignition of *submarine* charges were attended with greater difficulties than those which served to test the system in its application to land operations; nevertheless, the results ultimately attained were also of a character to lead to definite and favourable conclusions.

The method of establishing the connections of a charge with the wire and the earth differed naturally in some respects from the mode of proceeding already described.

The charges of powder were contained in canisters of block-tin carefully soldered so as to be water-tight. Any vessels of this material, such as turpentine cans, may be employed, provided they be perfectly coated inside with marine glue, or some other description of varnish.

The fuze, with two wires attached as before, the one a few inches longer than the other, was inserted into the charge, and fixed in its proper position in the canister by means of a loose-fitting bung, pushed a little distance into the neck, and cut on one side, so as to admit of the passage of the longer insulated wire, while the bare part of the shorter wire was firmly pressed by the cork against the inside of the neck. The latter was then completely filled up with melted gutta-percha, and the extremity of the short uncovered wire was bent back over its side, so as to be in close contact with the metal surface. In this manner the enclosed fuze was brought into good metallic connection with the wet earth or water by which the canister would be surrounded. See Fig. 1207.


1207.

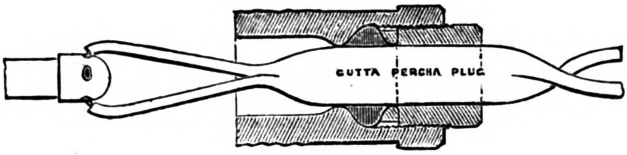
1208.

The insulated wire projecting from the mouth of the canister was connected with one of the branch wires in the manner already described, but, in order thoroughly to protect the connection from the water in which it would become immersed, a piece of vulcanized india-rubber tubing of suitable length, and a tin tube rather longer and wider than the latter, were slipped on to the branch wire, before it was joined to the fuze-wire; and when the junction had been effected, the india-rubber tube was pulled over it, and tied very firmly at both ends on to the gutta-percha covering of the wires. See Fig. 1208.

A small quantity of cement, consisting of beeswax and turpentine, was rubbed in between the gutta-percha and the ends of the india-rubber tube, so as thoroughly to ensure the exclusion of

water; and finally the tin tube was pulled over the joint, and fixed by compressing the ends, for the purpose of imparting rigidity to the junction, and thus protecting it from injury by a sudden twist or strain. By these arrangements the perfect exclusion of water from the charge, and from its connection with the branch wire, was effected. In an equipment prepared for effecting submarine explosions, by means of an electric current established by a permanent magnet, in China, stout bags of vulcanized india-rubber were provided for the reception of the charges. These bags were fitted with sockets and screw-plugs of gun metal. The fuzes furnished for use with these bags were attached to two pieces of covered wire, about 18 in. long, which were enclosed side by side in a cylindrical plug of gutta-percha, Fig. 1209, about 4 in. long, and carefully made to form

1209.




one mass with the coating of the enclosed wires. This plug was made to fit pretty tightly into a thick washer of india-rubber contained in the socket of the bag. An inner screw-socket, which was brought to bear with great force upon a metal ring resting on this washer, when the plug had been inserted, compressed its internal surface against the latter in such a way as to ensure a perfectly water-tight joint.

The first trials of these charges were made in a shallow canal with a mud bottom, and from which at the time of experiment the water was receding so rapidly, that before the whole of the charges had been immersed several of them were left half-imbedded in the mud. Twenty-five charges were arranged, of which thirteen were exploded, though less rapidly than in the experiments on land. On the next occasion, when twenty-five charges were regularly surrounded by water, simply resting upon the firm bed of a pond of some depth, only four of the charges were exploded. Several other attempts were made to fire a small number of (ten and five) charges similarly immersed, but in every instance only four were ignited. A careful examination into the cause of the invariable explosion of so comparatively limited a number of charges under water led to the following explanation.

It will be remembered that the explosion of numerous charges in a divided circuit by the magneto-electric apparatus with revolving *armatures* is effected by the action of an exceedingly rapid succession of currents. The rapidity with which they follow each other, however great, cannot equal that with which the terminals of a fuze (that explode a small charge under water) come into contact with the latter after the explosion. The instant this occurs a complete circuit is established through the water, and any further action of the currents is at once arrested.

By the time, therefore, that four charges had been ignited in extremely rapid succession, so as to be apparently exploded at once, a sufficient interval of time had in reality elapsed to allow the water to re-occupy the space filled for a brief period by the gaseous products of the first explosion, and thus to rush in upon and complete the circuit with the terminals of the fuze. The piece of soft iron K, when attracted by the temporary magnet 21, shown in Fig. 1193, is termed an armature.

It is believed that charges are generally so arranged for submarine operations as to be partially or completely surrounded by the objects upon which the force of the exploding charge is to be exerted, and that they are even at times firmly fixed in their position by being partly or wholly imbedded in sand, mud, or some similar material. In such cases the resistance to be overcome by the explosion is greater than if, under conditions otherwise similar, the charges were simply in direct contact with the water, and hence the interval is increased which must elapse before the water can complete the circuit of electricity.

The results of some experiments made at Chatham appear to show that, under such circumstances, the number of charges ignited at one time by the magneto-electric apparatus must be greater than if they were simply immersed in water. One experiment has already been mentioned, in which thirteen charges out of twenty-five were exploded at one time, most of them being imbedded in mud.

On another occasion the charges were placed in small pits filled with water, the canisters being covered in with mud beneath the latter. Nine of the charges were fired; the branch wire of the tenth was accidentally severed at the moment of the explosion, from its lying across one of the pits.

An attempt was made to fire simultaneously fourteen charges similarly arranged, by the current obtained from a large leave-magnet, but only seven were exploded; the other seven were fired on a second trial. It should be mentioned that the length of extended wire and the interval between the earth-connections were greater in these experiments than in those made at Woolwich with the large magnet, in which twenty-five charges were fired with perfect certainty by the single current obtained from it. Possibly the very great difference in the results obtained might have been partly due to some minute defects in the insulation of the branch wires employed at Chatham, which escaped notice on the inspection of the wires, but sufficed to diminish the intensity of the current when these were immersed in water.

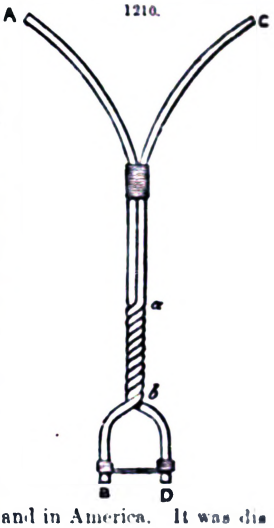
It is most difficult, even in a long-continued series of carefully-observed experiments, to separate the pure results furnished by the application of a system, from results which are brought about, or at any rate greatly modified, by accidental circumstances. It appears, however, apart from the latter, that in the application of electricity (whether frictional or magnetic) to the explosion of

charges the effects to be produced by the current are modified by the resistance offered to it in its passage along wires of very considerable length, and that the effects of the current seem very much less when the insulated wire is extended than when it is employed in the form of a coil.

The retardation in the explosion of several charges in divided circuit by a rapid succession of currents, and the diminution in the number of charges fired by one single powerful current, both of which results were repeatedly noticed in the course of the many experiments with the galvanic battery, and with the permanent magnet, could only be ascribed to modifications in the intensity of the electricity by the greater resistance which is encountered.

Robert Hare, Professor of Chemistry in the University of Pennsylvania, was the first who applied electricity to the explosion of mines. Hare found, if an electric current of sufficient force was established in a circuit (X Y Z, Fig. 1193) of copper wire by either a permanent magnet, or galvanic battery, that a short piece of iron wire (Q, Fig. 1193), much thinner than the copper wire, making part of the circuit (P R, 23, Fig. 1193), was burnt, and exploded gunpowder and other explosive substances through which the iron wire was made to pass. Hare's discovery may be practically applied by the following simple process:—Two copper wires, A B, C D, Fig. 1210, being procured, about $\frac{1}{10}$ in. in diameter and 10 ft. in length, well covered with silk or cotton tarred, so that their insulation may be good. These wires are twisted together for a length *a b* of 6 in., care being taken to leave their lower extremities, at B and D, free, for a length of about ½ an in. (separating them about ½ an in.); from the extremities B, D, the insulating envelope must be removed; and a fine iron wire is stretched between B and D. Metallic contact must be established between the iron and the copper. The upper extremities A, C, of the two copper wires are connected with a circuit. For example, if A, Fig. 1210, be connected with P, Fig. 1193, and C with R, the iron wire B D will be consumed as soon as a galvanic or electric current, sufficiently powerful, is established by inserting the contact-peg, M, Fig. 1193.

1210.




*Explosive Compounds Employed in Blasting.—Nitro-Glycerine* is a most powerful explosive agent, and although not extensively used in England, it has been most successfully employed on the Continent and in America. It was discovered by Ascagne Sobero, an Italian, in 1847, but its practical application to mining purposes is principally due to the researches of Alfred Nobel, a Swedish mining engineer.

Nitro-glycerine is made in the following manner:—Fuming nitric acid (sp. gr. about 1·52) is mixed with twice its weight of the strongest sulphuric acid, in a vessel kept cool by being surrounded with cold water. When this acid mixture is properly cooled, there is slowly poured into it rather more than one-sixth of its weight of syrupy glycerine; constant stirring is kept up during the addition of the glycerine, and the vessel containing the mixture is maintained at as low a temperature as possible by means of a surrounding of cold water, ice, or some freezing mixture. It is necessary to avoid any sensible heating of the mixture, otherwise the glycerine, which is the sweet principle of oil, would be, to a considerable extent, transformed into oxalic acid. When the action ceases, nitro-glycerine is produced. It forms on the surface as an oily-looking fluid, the undecomposed sulphuric acid forming the subjacent layer, owing to its greater specific gravity. The whole mixture is then poured, with constant stirring, into a large quantity of cold water, when the relative specific gravities become so altered that the nitro-glycerine subsides and the diluted acid rises to the surface. After the separation in this manner into two layers is effected, the upper layer may be removed by the process of decantation or by means of a siphon, and the remaining nitro-glycerine is washed and re-washed with fresh water till not a trace of acid reaction is indicated by blue litmus paper. The final purifying process, pursued by Nobel, is to crystallize the nitro-glycerine from its solution in wood naphtha. This final process is not necessary when the compound is to be used at once.

As prepared in this manner, nitro-glycerine is an oily-looking liquid, of a faint yellow colour, perfectly inodorous, and possessed of a sweet, aromatic, and somewhat piquant taste. It is poisonous, small doses of it producing headache, which may also be produced if the substance is absorbed into the blood through the skin, and hence it is not desirable to allow it to remain long in contact with the skin, but rather to wash it off as soon as possible with soap and water. Glycerine has a specific gravity of 1·25–1·26, but the nitro-glycerine has a specific gravity of almost 1·6, so that it is a heavy liquid. It is practically insoluble in water, but it readily dissolves in ether, in ordinary vinic alcohol, and in methylic alcohol or wood spirit. If it be simply exposed to contact with fire it does not explode, although it is so powerful as an explosive. A burning match may be introduced into it without producing any explosion, the match may be made to ignite the liquid, but combustion will cease as soon as the match ceases to burn. Nitro-glycerine may even be burned by means of a cotton wick or a strip of bibulous paper, as oil from a lamp, and as harmlessly. It remains fixed and perfectly unchanged at 212° Fahr.; if heated to about 360°, however, it explodes. It detonates when struck by the blow of a hammer, but only the part struck by the hammer explodes; the surrounding liquid remains unchanged.

As the carriage of nitro-glycerine is dangerous, many trials have been made to render it inexplosive, and to restore its explosiveness with equal readiness. Nobel's method of making it inexplosive is at once simple and effective. It is to mix with it from 5 to 10 per cent. of wood spirit, when all attempts at exploding it are rendered utterly futile. Five per cent. of methyl-alcohol is said to be amply sufficient to transform the nitro-glycerine into the inexplosive or pro-

tected state, but Nobel now always adds 10 per cent. before sending any of his blasting liquid into the market.

The transformation of protected into ordinary nitro-glycerine is effected by thoroughly agitating it with water, and allowing the mixture to settle for a short while. By this means the water dissolves out the methyl-alcohol, and the mixture of spirit and water readily rises to the surface, in virtue of its low specific gravity, and can be removed by means of a siphon, or by simply pouring it off. The blasting liquid is now ready for use. It would seem that the methyl-alcohol is by this means separated very readily from the nitro-glycerine held in solution by it. If protected blasting liquid be kept in a closed vessel, it will remain in that state for an indefinite period of time, and ready at any moment to be reduced or rendered fit for action; if, however, it be exposed in an open vessel, it will regain its explosiveness, in periods of time proportionate to the amount or degree of exposure.

The chief advantage which nitro-glycerine possesses is that it requires a much smaller hole or chamber than gunpowder does, the strength of the latter being scarcely one-tenth that of the former. Hence the miner's work, which, according to the hardness of the rock, represents from five to twenty times the price of gunpowder used, is so short, that the cost of blasting is often reduced 50 per cent. The process is very easy. If the chamber of the mine present fissures, it must first be lined with clay to make it water-tight. This done, the nitro-glycerine is poured in and water after it, which, being the lighter liquid, remains at the top. A slow match, with a well-charged percussion cap at the end, is then introduced into the nitro-glycerine, or a fuze, to the extremity of which is attached a small quantity of gunpowder, fixed immediately over the liquid. The mine may then be sprung by lighting the match, there being no need of tamping. Experiments were made with this new compound in the open part of the tin mines of Altenburg, in Saxony. In one of these, a chamber, 34 millimètres in diameter, was made perpendicularly in a dolomitic rock, 60 ft. in length, and at a distance of 14 ft. from its extremity, which was nearly vertical. At a depth of 8 ft., a vault filled with clay was found, in consequence of which the bottom of the hole was tamped, leaving a depth of 7 ft. One litre and a half of nitro-glycerine was then poured in; it occupied 5 ft. A match and stopper were then applied as stated, and the mine sprung. The effect was so enormous as to produce a fissure 50 ft. in length, and another of 20 ft. The total effect has not yet been ascertained, because it will require several small blasts to break the blocks that have been partially detached by this.

Nitro-glycerine has, however, one disadvantage. It freezes at a temperature very probably above 92° Fahr., and it is said that even at a temperature of 43° to 46° Fahr. the oil solidifies to an icy mass, which mere friction will cause to explode. It is probable, however, that the freezing-point of the oil lies somewhat lower than is here stated, though as yet no exact determination of the freezing-point of the oil has been made. A newspaper from Hirschberg, in Silesia, gives a sad account of an accident, caused by the frozen oil exploding by friction. Nitro-glycerine was there being used in making a tunnel. It was kept in glass vessels, packed in straw, and placed in baskets, each vessel containing one-fourth to one-eighth of a hundredweight of the oil. For several days the oil had been frozen. It was carefully handled, and pieces were separated by means of a piece of wood, and put into the bore-holes, and it was found that the frozen nitro-glycerine exploded quite as well as the fluid. One day an overseer at the shaft hit upon the unlucky idea of breaking into pieces with a pick a 700 or 800 lb. lump of the frozen glycerine. The blow caused the mass to explode, and the unfortunate man was blown up into the air, and fell back into the shaft, some 40 or 50 ft. deep, whilst two workmen, who were making cartridges a short distance from him, luckily escaped with slight injuries.

*Dynamite* is made by mixing 75 per cent. of nitro-glycerine with 25 per cent. of powdered sand (silica). It has been introduced by A. Nobel, whose researches on nitro-glycerine are so well known. Dynamite retains all the properties of nitro-glycerine for blasting, but is not dangerous, as it may be handled freely, and does not explode by fire alone or when accidentally subjected to percussion. In some experiments made by the inventor, a box containing about 8 lbs. of dynamite (equal in power to 80 lbs. of powder) was placed over a fire, where it slowly burned away. Another box containing the same quantity was hurled from a height of more than 60 ft. on to a rock below, no explosion ensuing from the concussion sustained. Explosion is produced by means of a percussion cap in the same manner as with nitro-glycerine.

*Schwartz's Blasting Gunpowder.*—This powder is now much employed in mining. Its combustion is slow but complete. The following analyses show why it is cheaper than ordinary powder:—

| | I. | II. |
|---|---|---|
| Soluble salts | 74·55 | 74·32 |
| Nitrate of potash | 56·22 | 56·23 |
| Nitrate of soda | 18·30 | 18·09 |

The treatment by sulphide of carbon produced:—

| | | |
|---|---|---|
| Dissolved sulphur | 9·68 | 7·61 |
| Carbon remaining | 14·14 | 15·01 |
| Moisture | 1·78 | 11 |

It is a coarse-grained powder, in which one part of potash nitre is replaced by nitrate of soda.

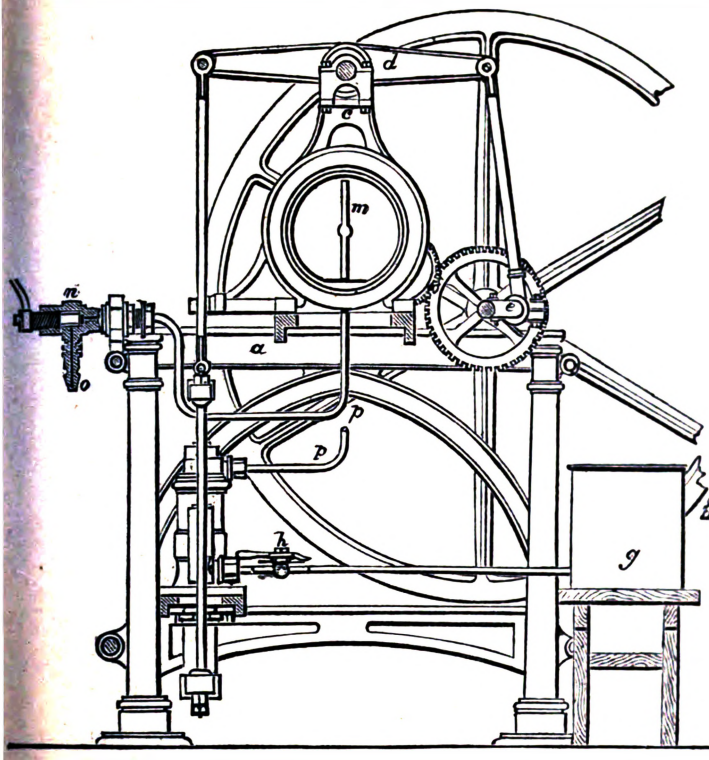
In the first instance, one part of nitrate of soda for one part of nitrate of potash was used, but it was afterwards found best to employ a third of nitrate of soda. See ARTESIAN WELLS. BATTERY. GUNPOWDER. GUN-COTTON. ORDNANCE. QUARRYING. TELEGRAPHY. TUNNELLING.

BOTTLING MACHINE. FR., *Machine à mettre en bouteilles;* GER., *Pfropfmaschine;* ITAL., *Macchina da toppar bottiglie.*

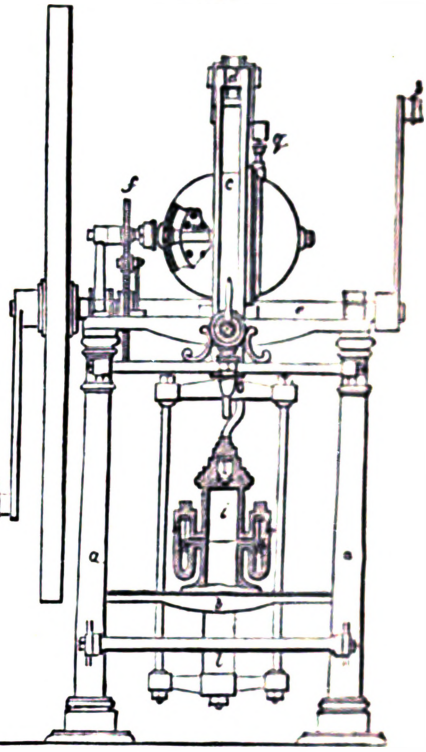
The bottling machine, shown in Figs. 1211, 1212, is chiefly used for soda and other aërated waters. It was invented by the late Hayward Tyler, and it is on the continuous principle. The

condenser and bottling-piece are shown in section Fig. 1211, to illustrate the internal construction. The same letters of reference refer to the same parts in Figs. 1211, 1212. Fig. 1211 is a side elevation, Fig. 1212 end elevation; one-half of the iron frame is taken away in Fig. 1211 to show

1211.

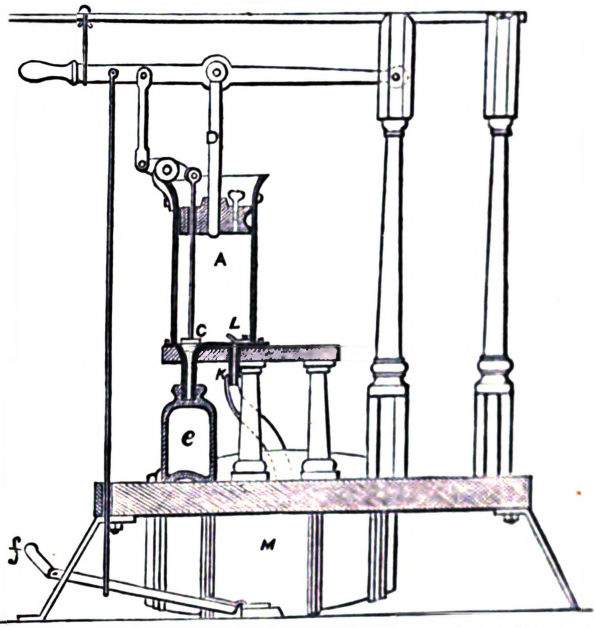



1212.




more clearly the working parts. The iron frame on which the whole of the working parts are fixed is removed for the same reason. *References*:—*b*, cast-iron stool for pump; *c*, carriage for condenser. *d*, wrought-iron beam, with connecting-rod to crank at one end, and side rods to the pump-piston frame at the other end; *e*, wrought-iron crank-shaft, with fly-wheel and two handles, *s*, *s*, which are used when hand-power is applied; *f*, brass wheel to work the agitator; *g*, copper solution pan; *h*, regulating cocks for gas and water, one only of which is shown; *i*, gun-metal pump, with separate valves for gas and water in the valve-pieces, which are marked *k k*. The delivery-valve is on the top of the pump; *l*, solid gun-metal piston working underneath the pump; *m*, agitator working inside the condenser to more intimately mix the gas and water together; *n*, bottling-piece fitted with a screw-valve and lever-handle; *o*, bottling nipple; *p p*, copper pipes, tinned inside, one to take the gas and water from the pump to the condenser, the other to convey them from the condenser to the bottling-piece; *q*, safety-valve to relieve the pressure in the condenser, in which there is also a pressure-gauge, not shown in the figures, to indicate the pressure suited to the different aërated waters. S, S, are handles for actuating the machine when worked by hand. The gas generator and gasometer, although not shown in Figs. 1211, 1212, are the same in all the machines employed for a similar purpose.

1213




W. F. Davidson's bottling machine, Fig. 1213, is arranged so that the liquid to be bottled is

drawn from the barrel M through a suction-pipe K by a piston, a valve L being arranged so as to prevent the return of the liquid. The liquid is let into the bottle *e* from the pump-cylinder A through the valve C, which is operated by means of levers and rods. This valve is closed by means of a spring bar acting automatically The plunger D is raised as soon as pressure is removed from the treadle *f*; thus giving an intermittent motion the work is continued.

BOTTOMING, OR BALLASTING. FR., *Empierrement*; GER., *Besteinung*, *Beschotterung*; ITAL., *Imbreuiare Inghiaiare.*

See PERMANENT WAY.

BOULDER-PAVING. FR., *Pavé en galet*; GER., *Rollsteinpflaster*; ITAL., *Ciottolato.*

See CONSTRUCTION.

BOULDER-WALLS. FR., *Mur en galet*; GER., *Rollstein Mauerwerk*; ITAL., *Muratura di ciottoli.*

See CONSTRUCTION.

BOUNDARIES. FR., *Limite*, GER., *Grenze*; ITAL., *Confine.*

In making a survey, the boundaries of the counties, parishes, and the several estates, are required to be marked correctly thereon; in ascertaining which, it is generally found necessary to procure the services of parties locally acquainted with the ground to be surveyed.

In the case of property divided by hedge and ditch, the brow of the ditch is generally the boundary; which, of course, forms the line to be measured. In some districts the roots of the quicks, or the foot of the bank, forms it: a width of 15 links is usually allowed for a hedge and ditch, 6 links for ditches between neighbouring estates, and 7 for those nearest roads, that is, from the roots of the quicks. See GEODESY. SURVEYING.

BOW-COMPASS. FR., *Compas à pompe*; GER., *Federzirkel*; ITAL., *Compassino da circoli.*

A pair of compasses for describing small circles with ink, is sometimes called a *bow-compass.* See COMPASSES.

BOW-PEN. FR., *Tire-ligne*; GER., *Reissfeder*; ITAL., *Penna a serbatoio.*

This pen is often termed a *drawing pen:* the part of it which holds the ink is formed of two cheeks which are bowed out towards the middle, and regulated by a screw. See COMPASSES.

BOW-DRILL. FR., *Archelet*; GER., *Drillbojen*, *Fidelbogen*; ITAL., *Trapano ad archetto.*

See HAND-TOOLS.

BOW-SAW. FR., *Scie à chantourner*, *scie en archet*; GER., *Schweifsäge*; ITAL., *Seghetto.*

See HAND-TOOLS.

BOX.

A cylindrical, hollow iron, used in wheels, in which the *axle* revolves, is called an axle-box.

A *box-drain* is a term generally applied to a small drain with vertical sides. See DRAINAGE.

BOXING OF A SHUTTER.

The part into which a shutter is folded when not required for use. It is formed by the inside lining of the sash-frame, the grounds of the architrave, and the *back lining.* See SASH-FRAME.

BOYAU. FR., *Boyau*; GER., *Gang des Laufgraben*; ITAL., *Ramo di trinciera*; SPAN., *Ramal.*

Boyaux, or boyaus, are small trenches, or branches of a trench, leading to a magazine, or to any particular point. See FORTIFICATION.

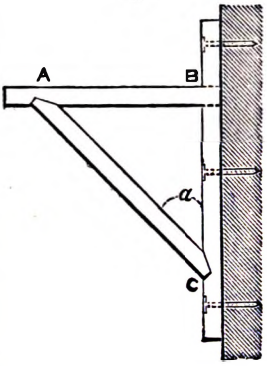
BRACE.

A brace is that part of a piece of framing which is subject to tension or compression, such as the diagonal bars of a Warren girder. It differs from a *strut*, which is subject to compression; or from a *tie*, which is subject to tension only. See BRIDGES.

BRACKET. FR., *Palier*, *console*, *tasseau*; GER., *Unterlage*, *Lager*, *Consol*; ITAL., *Mensola*, *Beccatello.*

A bracket is an arm which projects from the face of a wall or post, chiefly used to sustain a shelf, roof, cornice, or other overhanging structure. It is usually supported at the outer end by a strut, as A C, Fig. 1214. The strain tending to pull the bearer A B out of its socket at B is represented by W tan *a*; and that portion of the load which is transmitted to the wall along the strut A C is represented by $\frac{W}{\cos. a}$; W being the weight assumed to be concentrated at the point A, and *a* the angle which the strut makes with the wall. When the load is distributed over the bearer A B, the strains on it and on the strut A C will be reduced to one-half. The vertical strain or pressure on the wall or *upright* of the bracket will be equal to the load. A distributed load will cause a transverse strain on the bearer itself, in the same manner as a beam supported at both ends, or supported at one end and fixed at the other, as the case may be. In a solid bracket, or one of ornamental shape, as Fig. 1215, the strain at B is all that is usually required, and may be ascertained on the prin-

1214.

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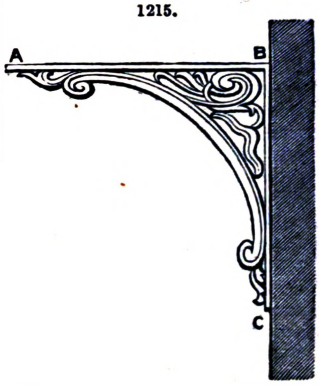


ciple of the lever. It will equal $\frac{W \times AB}{BC}$ for a load concentrated at A, and one-half that quantity when the load is distributed. See STRENGTH OF MATERIALS.

In large cornices, to save plaster it is usual to fix to the wall and ceiling, at intervals of 12 or 14 in., brackets cut roughly to the outline of the intended cornice: to these, laths are nailed, to take the plaster of the cornice. The brackets in the angles are called *angle-brackets*.

The term *bracket* is also applied to a projecting arm which carries on its end a gas-burner. Pieces of wood fixed on the end of the tread of stairs over the outer string-board are called brackets; they are sometimes made ornamental, in which case they are called *wreathed* or *fancy brackets*; in other cases they are known as *cut brackets*. Brackets in stone are usually called *corbels*.

BRAKE, OR BREAK. FR., *Frein*; GER., *Bremse*; ITAL., *Freno*.

A piece of mechanism for retarding or stopping motion by friction, as of a carriage or railway train, by the pressure of rubbers against the wheels. In Fig. 1216 the hand-wheel on the spindle A, which is fastened to the platform R of the car, winds up the chain F, and pulls the lever B, which presses the brake-block H upon the wheel G, and pulls the rod S, which presses the brake-block upon the wheel D, and pulls the rod E, which runs to the next truck, where there is a duplicate of the arrangement, shown in Fig. 1216. Thus, turning the brake-wheel at either end of the car brings an equal pressure upon all the wheels.

1216.

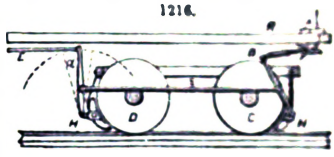
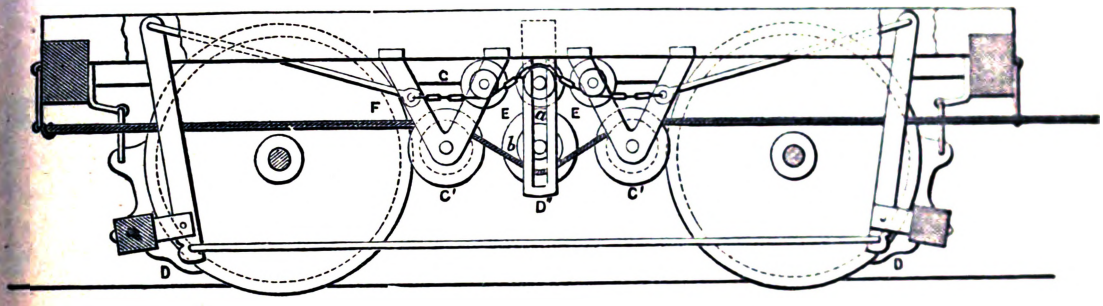


Fig. 1217 shows a railroad car brake, invented by A. J. Ambler; it belongs to that class of railroad brakes in which a tensional chain, or rods and chains, are used for operating or applying power from the locomotive to the brakes of a train of cars.

1217.




This arrangement of Ambler consists of fixed and sliding sheaves E, E, in connection with a tensional chain F, and brake-chain G so that by operating the tensional chain F a movement will be imparted to the brake-chain G, to set or apply the brakes D, D. The slack of the tensional chain F will be taken up by the falling of the sliding sheaves E, E, when the power is removed from the chain F. The power of the brakes is limited and controlled by limiting the rising and falling movement of the *sheaves* E, E, by having the *axles b* of the sheaves fitted into slots *a* in the bars D'' D''. The sheaves C', C', are stationary.

The number of brake carriages or vans to a given train will depend on the inclinations on the line and the speeds employed: with passenger trains it has been considered that on an average, and to ensure safety, every fifth carriage should have a brake, the engine also is generally reversed to assist the brakes. It must be recollected, however, that by stopping a train too rapidly, great injury results both to the permanent way and the rolling stock. But still it is very important that those who have charge of a train should be able to stop it within a very short distance, when there is risk of collision, or any other danger is apprehended; and the greater the number of wheels to which brakes are applied, the more speedily will the effect be produced.

The following considerations appear to be those which would determine the amount of brake-power.

The forces which act on the train after the steam has been shut off are the axle friction and rolling friction of the train, and the pressure of the wind: the friction tends gradually to bring the train to rest,—the pressure of the wind to accelerate or retard it, as the case may be, and this will therefore be omitted from the conclusions to be drawn.

To stop a train rapidly, brakes are applied to some of the wheels, and the engine is reversed. The application of brakes prevents the wheels from revolving, and introduces the friction due to the weights on the wheels to which the brakes are applied. The act of reversing the engine does not immediately stop the forward motion of the driving-wheel, but forces it to revolve at a some what slower rate than that due to the speed of the train, and thus causes a friction of surfaces to take place between the wheel and rail.

The axle and rolling friction of the train may be assumed to be some proportion of the total weight of the train: the friction of the wheels to which brakes are applied may be taken as some proportion of the insistent weights; from experiments, it appears that the axle and rolling friction may be taken at $\frac{1}{350}$ part of the weight of the train, and the friction due to the brakes at about $\frac{1}{4}$ of the weights on them.

Hence, if $l$ represent the gross load of the train,
$w$ „ the weights on the wheels to which brakes are applied,
R „ the retardation in feet per second,
$g$ „ the force of gravity,
and, if the train be on an incline,
$\frac{1}{p}$ represent the slope of such incline,

$$R = \left(\frac{l-w}{334} + \frac{w}{8} \pm \frac{1}{p}\right)\frac{g}{l}.$$

the latter term being used with the negative sign when the train is descending, and the positive sign when ascending, the gradient.

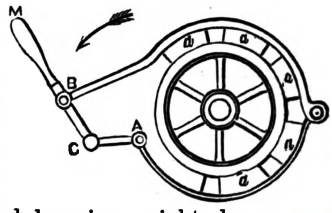
If S = space traversed by train in coming to rest,
$v$ = velocity in feet per second at the moment the steam is shut off and the brakes applied

$$S = \frac{v^2}{2R}$$

It should be observed that these estimates and formulas, although empirical, may be found useful in forming rough estimates; and that, in estimating practically the space of time which should be required for a train to stop in, one or two seconds should be allowed for time lost in applying the brakes. These combinations will be referred to presently.

Speaking in general terms, a brake consists of one or several segments of wood or metal, which can be pressed upon the circumference of a wheel, so as to produce friction, which, acting as a resistance, reduces the velocity of that wheel. Fig. 1218 represents a brake so constructed; the wooden blocks $a$, $a$, $a$, $a$, are connected by two straps of iron, movable round a fixed point O; the ends A and B of these two straps are fastened to the *bell-crank* A C B. As none of the centres of motion, A, B, C, are fixed, the arms A C, C B, have the power of a toggle-joint. If the handle M of the bell-crank is moved in the direction indicated by the arrow, the blocks are forced to press upon the rim of the wheel, and friction is thus produced, which diminishes the velocity of the wheel which is supposed to be in motion. In order to distribute the pressure over a large surface, so that the materials in contact be not altered, the brake should necessarily embrace a sufficient part of the circle. Cranes, and generally all machines for lifting and lowering weights by means of handles, are provided with a brake acting upon a special wheel which influences the movement of the chain barrel.

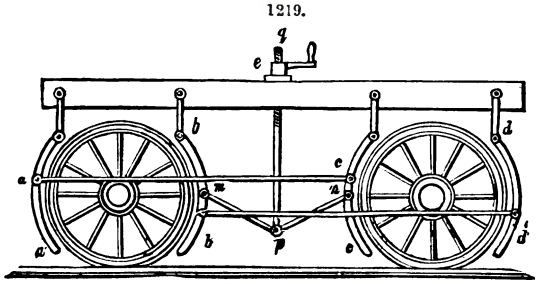
1218.




Also trains of great velocity are either stopped on inclines or their motion is retarded on railroads, as is well known, by applying a brake to the carriages. The brakes of common carriages are wooden blocks placed near the back wheels; by means of a handle and a screw, acting upon system of levers, the blocks are pressed upon the rims of these wheels. These brakes are substituted with advantage for the ancient wooden shoe or sabot, which is still used by carters or wagoners; the use of that shoe is to prevent the wheel from turning, and it transforms the rolling friction into a sliding friction, which is much more considerable; it produces thus a resistance which tends to diminish the velocity of the carriage and to prevent its acceleration in descending inclines. But the use of the shoe is very incommodious, and serious accidents may happen if the chain, which holds the sabot or shoe, breaks. The brake acts in a more gradual manner, and its use is handier and safer.

In railway trains the brakes act simultaneously upon all wheels of the same carriage. Various constructions have been adopted for that purpose. Fig. 1219 shows one of the earliest, as used on the Versailles railway. The equal segments $a\,a'$, $b\,b'$, $c\,c'$, $d\,d'$, are placed at a little distance before and behind each wheel; they are suspended from the frame of the carriage by rods moving round fixed points. The levers $m\,p$ and $n\,p$, jointed to the middle of the arcs $b\,b'$ and $c\,c'$, are connected at $p$ with a vertical rod $p\,q$, which has a screw at its end, and is raised or lowered by means of the nut $e$. The raising of the point $p$ brings the points $m$ and $n$ nearer to the wheels, with the power of a toggle-joint, and the arcs $b\,b'$ and $c\,c'$ are pressed against the tires with great force; the same takes place with the arcs $a\,a'$ and $d\,d'$, which are connected with the arcs $b\,b'$ and $c\,c'$ by means of the coupling-rods $a\,c$ and $b'\,d'$; in this manner four arcs or blocks press upon the wheels at the same time. The blocks are either made of wood and hooped with iron, or they

1219.

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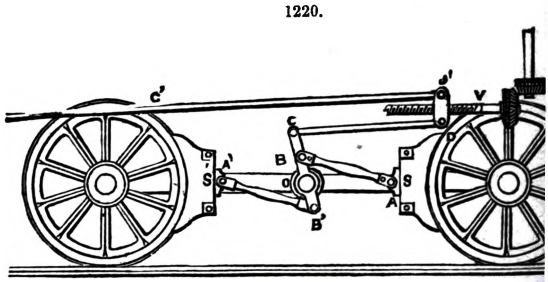
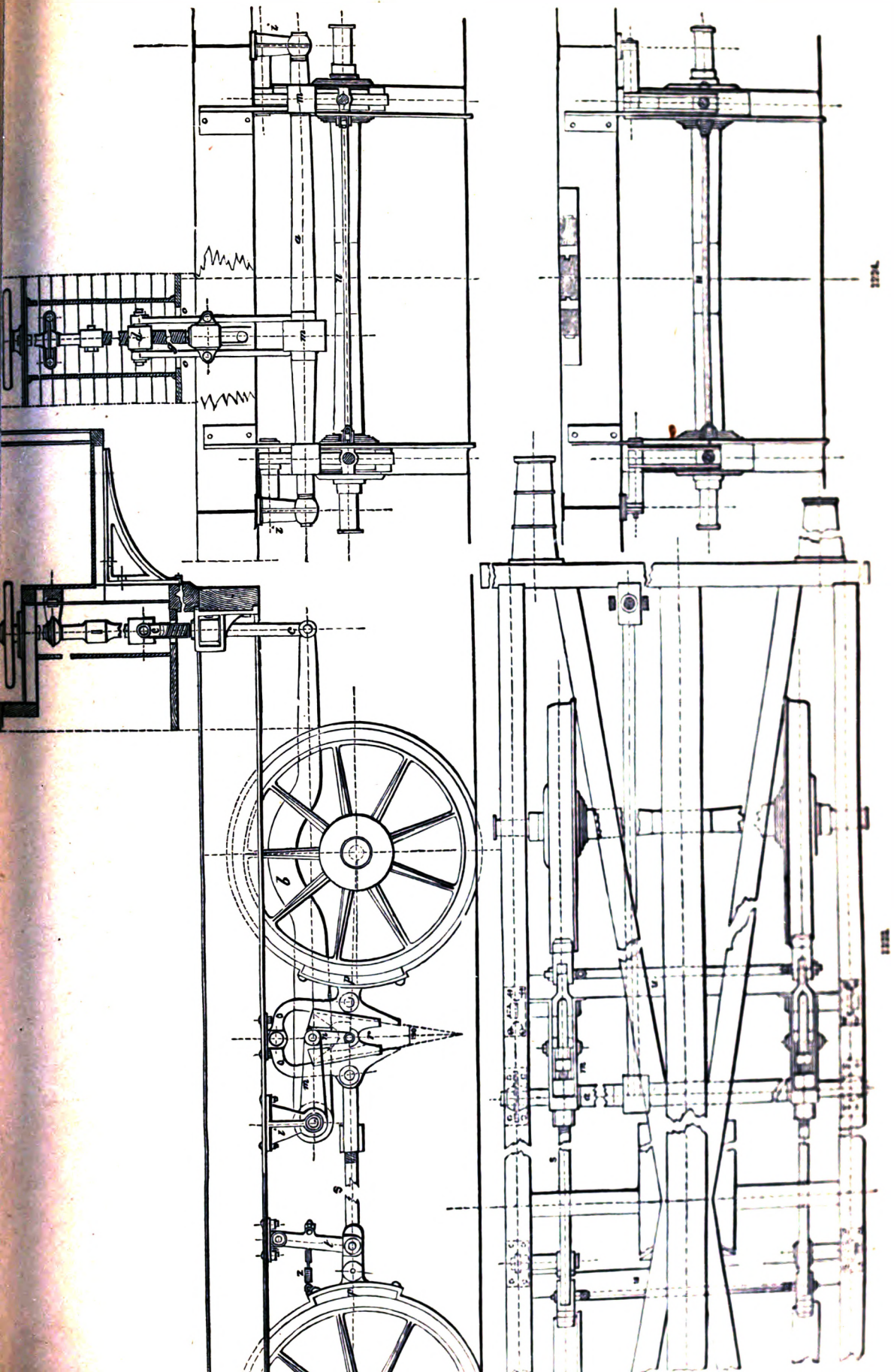



are made entirely of iron. Fig. 1220 represents a brake operated by compound levers: in general, this latter principle of construction is adopted.

The two brake-blocks S and S', Fig. 1220, are connected with two equal levers A B and A' B,



which are again fastened to a third lever B' B C, movable round a shaft O. The rod C D connects the end C of the lever B' B C with the nut D D', which is moved backwards and forwards by the screw V this screw, which can only move round its axis, but not in a longitudinal direction, is turned by wheel-gearing from the box of the guard or brakes-man. Therefore, by turning the brake-wheel to the right, the nut D D' advances to the right and pulls the points C and B into the same direction, whilst the point B' is pushed into the opposite direction, and the brake-blocks are consequently pressed upon the tires of the wheels. The coupling-rod C' D', jointed at D', produces an analogous effect upon the following wheels. The reverse takes place if the brake-wheel be turned in the opposite direction, that is, the blocks S, S', are then removed from the wheels.

In order to bring the brake into full action a certain time is always required, and numerous constructions have been adopted for shortening this time as much as possible. One method is that of employing a weight of an oblong form with a rack and pinion on its longest vertical side: this weight moves between guides in a vertical direction, and is kept in its place by means of a click or spring. As soon as the guard removes the click or eases the spring, the weight falls, and turning the pinion rapidly round its horizontal axis, transfers the motion to the brake-blocks, which act in the manner previously described. By means of a handle the pinion is turned in the opposite direction, the weight is raised, and again fastened in its former position. It will be seen that the action of the brake under these circumstances must be very rapid, and a train can be stopped in a very short time.

But the advantages of this very great rapidity should not be exaggerated; a train should not be stopped instantaneously. To stop quickly is equal to a sudden shock against an obstacle, and might produce serious accidents. M. Gentil, mining engineer, has compared that shock with the one which the train would sustain by falling vertically from a certain height: the following Table gives the results of his researches:—

| Trains. | Speed an hour, in kilomètres. | Speed a second, in mètres. | Height of Fall, in mètres. | Comparison. | Remarks. |
|---|---|---|---|---|---|
| | kilos. | m. | m. | | |
| Goods train .. | 25 | 6·94 | 2·456 | Ground floor | The consequences of the shock of an express train suddenly stopped, would be the same as if that train had fallen from a fourth floor, or from a height of 46 ft. |
| Mixed .. .. | 30 | 8·33 | 3·533 | 1st „ | |
| Passenger .. | 40 | 11·11 | 6·293 | 2nd „ | |
| Mail .. .. .. | 50 | 13·88 | 9·825 | 3rd „ | |
| Express .. .. | 60 | 16·66 | 14·159 | 4th „ | |

The law in France demands one brake-van to seven carriages or less; two brake-vans if the number of carriages varies between seven and fifteen; three brake-vans for a train of more than fifteen carriages; the tender-brakes are not included in that number.

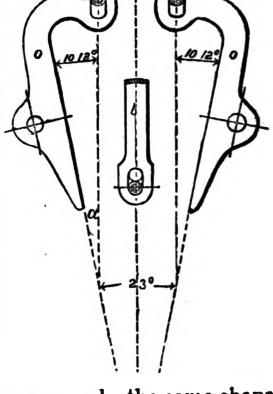
On the Turin-Genoa railway one brake-van to two carriages of a passenger train is allowed; and three wagons of a goods train to a brake-van.

In Prussia $\frac{1}{6}$ of the total number of wheels of a passenger train, and $\frac{1}{8}$ of the wheels of a goods train, have to be provided with brakes, if the inclination of the line is not more than $0^m \cdot 0033$ the mètre. For an inclination between $0^m \cdot 0033$ and 0 ·005, $\frac{1}{5}$ and $\frac{1}{7}$ have to be substituted for these fractions, and $\frac{1}{4}$ and $\frac{1}{6}$ for an inclination between $0^m \cdot 005$ and $0^m \cdot 010$.

Figs. 1221 to 1224 represent the arrangement of Stilmant's brake.

It is apparent from these figures that the horizontal shaft *a*, supported by the brackets *i i*, is moved by means of a long lever *b*, which is connected at its end, by the two rods *c c*, with the nut *d*; this nut being raised or lowered by the spindle *g*, transfers thus its motion, not only to the lever *b* and the shaft *a*, but from there also by means of the forked levers *m*, *m*, and the rods *n*, *n*, to the wedges *r r*. These wedges are made of cast iron, and form two symmetrical parts, which are supported by means of a joint or hinge; four sliding parts *o*, *o*, two of which carry directly the brake-blocks *p*, *p*, whilst the two others are kept in their respective positions by means of the pressure-rods *s*, *s*, serving as guides to the wedges.

1225.




The greatest angle formed by these sliding parts and the wedges, during the inactivity of the brake, is 23 degrees; at the moment of putting the brake in action this angle becomes less, since the sliding parts are pressed more towards the outside; and at the greatest pressure of the wedges against the sliding parts the angle is about 19 degrees.

The thread of the brake-screw *g* ought to be double, so that the lever *b*, the end of which has to pass through a very considerable arc, can be moved as quickly as possible. The brake-blocks which are not directly fastened to the wedges are kept in their respective positions by means of the suspension-rods *t t*, and the horizontal rods *u u*. The spiral springs *z z* keep the brake-blocks during the inactivity of the brake at a sufficient distance from the tires, and thus prevent any unnecessary friction. The free action of the suspension-springs during the stopping of the wheels has now been obtained simply by bending the sliding parts *o*, *o*, which serve as guides for the wedges *r r*, to a certain angle, and by making the holes in these sliding parts more oval; the same shape is given to the hole at the lower part of the suspension-rods *t t*, that is to say, where these rods

are fastened to the coupling-rods *s s*, Fig. 1225. The chief centre lines of the holes in the sliding parts form with the side *a b* an angle of 10 or 12 degrees; the diameter of these holes is 41 millimètres their length 61 millimètres, thus giving to the springs a play of 20 millimetres, sufficient for the oscillations during the running of the wagon.

A few words may be said here with respect to brake-blocks in general, and with respect to iron blocks in particular. Some time ago brake-blocks were made of soft wood, such as elm, beech, poplar, and so on, which is less susceptible to become polished by friction than iron; the rapid wear and tear, however, requiring often and expensive renewing of the blocks, have induced many engineers to substitute metal, and especially iron, in place of wood.

The use of self-acting brakes in engines of Engerth's system requires great care in descending inclines of 8 millimètres near Loxeville. The wooden brake-blocks of the tender catch fire very often, and are entirely destroyed when the train reaches the station. In order to prevent this inconvenience, iron blocks have been substituted for the wooden ones.

The following are the results of that application:—

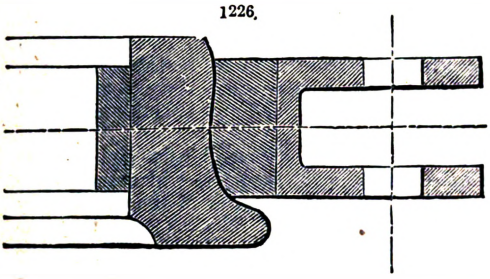
1. With wooden brake-blocks the wheels of the tender had to be stopped in order to prevent heating and the returning of the tires after a run of 9000 kilomètres. Since iron brake-blocks are adopted on some of the French railways, the wheels are allowed to turn slowly in descending inclines; several tenders have already run over 12,000 kilomètres without the tires of the wheels requiring to be cooled.

2. The wear and tear of the iron brake-blocks has been 14 or 15 millimètres for an average distance of 15,000 kilomètres.

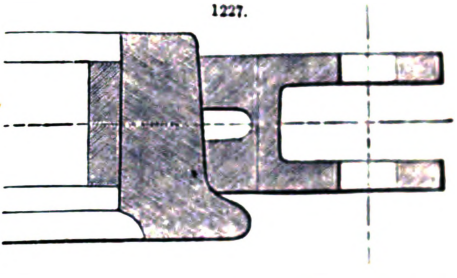
Those results have been fully confirmed by the experiments made with Stilmant's brake; and it has since been found that a better retardation of the motion of the train is obtained if the blocks are not pressed upon the wheels during the whole time required for the stopping of a train, but are lifted up and pressed upon again at very short intervals.

It has been, however, observed that the tires of the wheels, especially those of the tender, and the iron brake-blocks used at present, acquire very quickly, not only the shape shown in Fig. 1226, but often deep grooves are cut around the whole circumference of the tires. These grooves are produced either by grains of sand, which find their way between the tires and the brake-blocks, or by impurities of the iron. In order to prevent this disadvantage, M. Stilmant has proposed brake-blocks of cast steel, shown in transverse section, Fig. 1227. The surface of these blocks, which comes in contact with the tires of the wheels, is divided into two equal parts of 32 millimètres width; the central groove has a width of 20 millimètres and a depth of 36 millimètres, which gives sufficient room for a current of air to pass through.

1226.



1227.



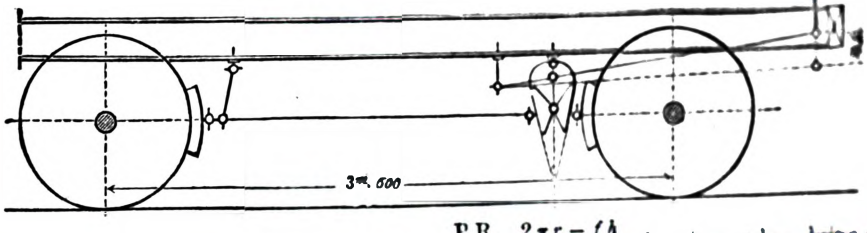
*To find by Calculation the Pressure and Power of this Brake.*—It will be seen from Fig. 1228 that the brake is composed of a combination of different simple machines, which can act each separately, and transfer the produced effect successively from one upon the other, and accumulate thus a very considerable pressure, which it would be impossible to obtain, under the same conditions, by one or the other of these simple machines alone.

The obtained pressure is very variable, and depends chiefly upon the power exercised by the guard upon the handle or wheel of the screw.

Referring to Fig. 1228, and putting

$R = 0^m \cdot 220$, the length of the handle or the radius of the brake-wheel;
$r = 0^m \cdot 023$, the radius of the brake-screw;
$h = 0^m \cdot 044$, the thread of the screw;
$f = 0 \cdot 08$, the coefficient of friction of the screw; and
$P = 30^k$. the force of the guard on the handle or the wheel;

1228.




we get as the work of the screw the pressure $Q = \frac{P R}{r} \times \frac{2\pi r - fh}{h + 2\pi r f}$: the given values being sub-

stituted, we have $Q = \frac{30 \times 0{\cdot}22}{0{\cdot}023} \times \frac{2 \times 3{\cdot}14 \times 0{\cdot}023 - 0{\cdot}08 \times 0{\cdot}044}{0{\cdot}044 + 2 \times 3{\cdot}14 \times 0{\cdot}023 \times 0{\cdot}08} = 727^{k}{\cdot}89$, or about 728 kilogrammes.

The effective weight of the suspension-rods $c\,c = 16^{k}$ has to be added to this pressure, so that the total force at the end of the lever $b$ is equal to $Q = P_2 = 728 + 16 = 744$ kilogrammes

Calling, therefore,

$L = 2^{m}{\cdot}065$, the length of the lever $b$;
$p = 80^{k}$, its own weight reduced to the centre of gravity;
$L_1 = 0^{m}{\cdot}970$, distance of centre of gravity from the centre of the horizontal shaft;
$l_1 = 0^{m}{\cdot}365$, length of the small levers;
$p_1 = 18^{k}$, weight of the lever reduced to its centre of gravity; and
$l_1 = 0^{m}{\cdot}200$, distance of centre of gravity from the centre of the horizontal shaft;

the pressure produced by the lever is equal to $Q_1 = \frac{P_1 L + p L_1 + p_1 l_1}{l}$; or substituting again the given values, $Q_1 = \frac{744 \times 2{\cdot}065 + 80 \times 0{\cdot}97 + 18 \times 0{\cdot}2}{0{\cdot}365} = 4431^{k}{\cdot}67$, or very nearly 4432 kilogrammes.

Adding again the effective weights of the suspension-rods $n\,n$, of the bolts for the joints of the wedges, &c., equal to 53 kilogrammes, we get the total pressure produced upon the wedges,

$$Q_1 = P_2 = 4432 + 53 = 4485 \text{ kilogrammes.}$$

Taking, finally, the angle formed by the two parts of the wedges at the moment the brake is applied, $\alpha = 19°$, therefore $\beta = 80°\ 30'$, and $f_1 = 0{\cdot}18$ the coefficient of friction of the wedges, we get altogether the considerable pressure of $Q_2 = \frac{\text{tang. } \beta + 2 f_1 + f_1^2 \text{ tang. } \beta}{2 (1 + f_1 \text{ tang. } \beta)} \times P_2$, or

$$Q_2 = \frac{\text{tang. } 80°\,30' + 2 \times 0{\cdot}18 + 0{\cdot}18^2 \times \text{tang. } 80°\,30'}{2 (1 + 0{\cdot}18 \times \text{tang. } 80°\,30')}$$

$Q_2 = 2{\cdot}699 \times 4485 = 12105$ kilogrammes, which gives a pressure upon each brake-block of $\frac{Q_2}{4} = \frac{12105}{4} = 3026$ kilogrammes.

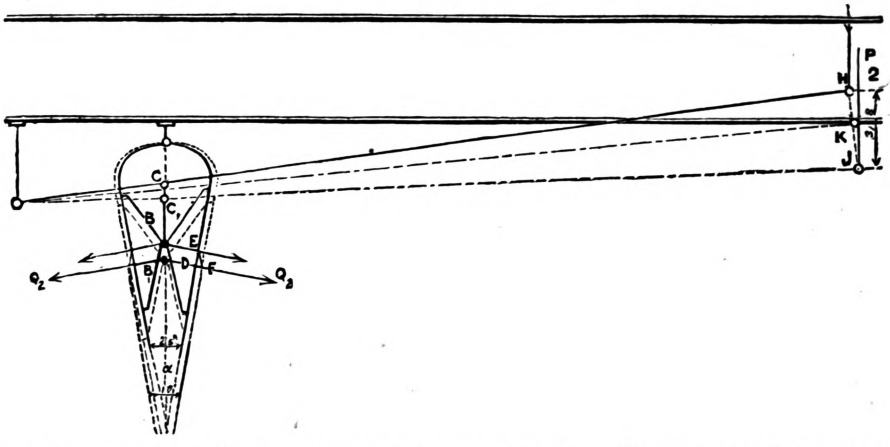
This pressure is considerably increased by the impulse given to the blocks from the wheels as they rotate; according to experiments made with the pressure or coupling rods $s\,s$, it can be taken as 4500 or 5000 kilogrammes. Now, if the coefficient of friction of the block be put equal to $0{\cdot}4$, the effort of this friction will be $T = 4500 \times 0{\cdot}4 = 1800$ kilogrammes, which is much greater than the adhesion of the wheels.

*Time required for the Action of the Brake.*—Although the stopping of wheels by means of screw-brakes is generally considered a slow operation, yet stopping a train by Stilmant's system is an exception, on account of the rapidity of its action, which is as prompt as in the best constructions, while at the same time it possesses many other advantages. Besides, the small space between the brake-blocks and the tires of the wheels very much facilitates the quick and effective action of Stilmant's brake.

Supposing now that in a well-constructed brake the distance between blocks and tires is equal to $0^{m}{\cdot}003$, and taking the play between the axle-boxes and the plates in which they move to equal $0^{m}{\cdot}003$, we find:—That the friction between the blocks and the tires of the wheels only commences when the blocks will have passed through a distance of $0^{m}{\cdot}003$ ($a$); and that the braking of the wheels takes place immediately after a distance of $0^{m}{\cdot}006$ (which may be less) is passed ($b$).

It is thus necessary to determine the distance $B\,B_1 = C\,C_1$, Fig. 1229, which the wedges have to travel before the blocks touch the wheels

1229.




For this purpose we find in the triangle E D F, at first, that $E = \frac{\alpha}{2} = 11° 30'$, and $D\,F = 0^{m}{\cdot}003$; next, that $E = \frac{\alpha}{2} = 9°\ 30'$, and $D\,F = 0^{m}{\cdot}003$; and consequently ($a$) for the contact between blocks and tires; $E\,F = B\,B_1 = D\,F$ cotang. E, or $B\,B_1 = 0{\cdot}003$ cotang. $11° 30' = 0^{m}{\cdot}01472$,

whence the distance travelled by the end of the long lever $b$, $H K = \frac{0{\cdot}014 \times 2{\cdot}065}{0{\cdot}365} = 0^m{\cdot}0834$, or the number of revolutions of the handle of wheel, if the thread of the screw is equal $0^m{\cdot}044$, $n = \frac{0{\cdot}0834}{0{\cdot}044} = 1{\cdot}9$ revolutions. For the stopping of the wheels ($b$), $E F = B B_1 = D F$ cotang. E, $B B_1 = 0{\cdot}003$ cotang. $2^\circ 30' = 0^m{\cdot}01793$, whence the distance travelled by the lever,

$$K J = \frac{0{\cdot}01793 \times 2{\cdot}065}{0{\cdot}365} = 0^m{\cdot}1014,$$

and the number of revolutions of the handle or brake-wheel $n = \frac{0{\cdot}1014}{0{\cdot}044} = 2{\cdot}3$. Thus the total distance through which the end of the lever $b$ has to move will be $H J = 0{\cdot}0834 + 0{\cdot}1014 = 0^m{\cdot}1848$, or $n = \frac{0{\cdot}1848}{0{\cdot}044} = 4{\cdot}2$ revolutions, requiring about 10 or 12 seconds. An express train, running 60 kilomètres an hour or $16^m{\cdot}66$ a second, can therefore be stopped by means of two of Stilmant's brakes upon a length of less than 500 mètres; this result has been corroborated by experiments.

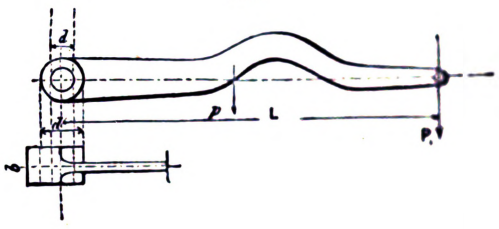
*Construction of, and Work done by, the Principal Parts of the Brake.*—Amongst the many parts which compose the mechanism of the brake, there is a certain number, the dimensions of which ought to be carefully calculated. These parts are:—The shank of the screw ($a$); the rods transmitting the pressure of the screw to the lever ($b$); the main lever ($c$); the two small levers ($d$), the brake-shaft ($e$); and the coupling or pressure rods ($f$).

*Screw of the Stem or Shank of the Brake* ($a$).—Suppose the minimum diameter of the stem of the screw, Fig. 1230, be $0^m{\cdot}035$. and taking the same values given above, we get $P r = \frac{R_1 J}{n}$, or substituting for $\frac{J}{n}$ its value $= \frac{\pi d^3}{16}$, $P r = \frac{R_1 \pi d^3}{16}$, whence $R_1 = \frac{16 P r}{\pi d^3}$; or introducing the values, $R_1 = \frac{16 \times 30 \times 0{\cdot}22}{3{\cdot}14 \times 0{\cdot}035^3} = 784400$ kilogrammes, or about $0^k{\cdot}800$ to the square millimètre. Taking the modulus of elasticity for the torsion, G = 6600000000 kilogrammes, we find the angle of torsion, $t = \frac{P r L}{J G}$. or substituting again for J its value $= \frac{\pi d^4}{32} 0{\cdot}098\, d^4$, $t = \frac{P r L}{0{\cdot}098\, d^4 G}$, or $t = \frac{30 \times 0{\cdot}22 \times 1{\cdot}5}{0{\cdot}098 \times 0{\cdot}035^4 \times 6600000000} = 0^\circ{\cdot}0102$, that is to say, $0^\circ\ 0'\ 36''7$.

1230.

1231.

1232.




*Rods Transmitting the Pressure to the Lever* ($b$), Fig. 1231.—The pressure which has to be transmitted, as has been shown previously, is equal to 744 kilogrammes; therefore for each pair of rods (there being always two) $\frac{744}{2} = 372$ kilogrammes. We thus obtain $P L^2 = \pi^2 J E$; or substituting for J its value $= \frac{b^3 h}{12}$, $P L^2 = \frac{\pi^2 b^3 h E}{12}$, whence $E = \frac{12 P L^2}{\pi^2 b^3 h}$.

When the corresponding values are introduced, we have

$$E = \frac{12 \times 372 \times 0{\cdot}9^2}{3{\cdot}14^2 \times 0{\cdot}02^3 \times 0{\cdot}045} = 1018546500 \text{ kilogrammes.}$$

Now, $E = \frac{P L}{A E}$, whence $i = \frac{P L}{A E}$; or substituting the values,

$$i = \frac{372 \times 0{\cdot}9}{0{\cdot}0009 \times 1018546500} = 0^m{\cdot}000365.$$

$i$ is the shortening and A the area of the transverse section of the rod.

*The Main Lever* ($c$), Fig. 1232.—The force acting at the end of the lever is again, as in the case above, P = 744 kilogrammes, besides the weight $p$ of the lever, which acts at its centre of gravity.

The equation for equilibrium will be $(P + \frac{1}{2} p) L = \frac{RJ}{n}$; or substituting for $\frac{J}{n}$ its value, we obtain, for the section taken in the central axis, $(P + \frac{1}{2} p) L = \frac{R b (h^3 - h_1^3)}{6 h}$, whence

$$R = \frac{6 h (P + \frac{1}{2} p) L}{b (h^3 - h_1^3)}, \text{ or } R = \frac{6 \times 0{\cdot}17 \times (744 + 40) \times 2{\cdot}065}{0{\cdot}13 \times (0{\cdot}17^3 - 0{\cdot}09^3)} = 3036100 \text{ kilogrammes,}$$

say about 3 kilogrammes to a square millimètre; for the section taken before the centre, $(P + \frac{1}{2} p) L = \frac{R b h^2}{6}$ whence $R = \frac{6 L (P + \frac{1}{2} p)}{b h^2}$, or $R = \frac{6 \times 1{\cdot}98 (744 + 40)}{0{\cdot}04 \times 0{\cdot}17^2} = 8057024$ kilogrammes, that is to say, about 8 kilogrammes per square millimètre.

The flexure of the lever is obtained by the formula $f = \frac{4 (P + \frac{1}{2} p) L^3}{E b h^3}$, or

$$f = \frac{4 \times 784 \times 2{\cdot}065^3}{20000000000 \times 0{\cdot}04 \times 0{\cdot}17^3} = 0^m{\cdot}007; \text{ say, 7 millimètres.}$$

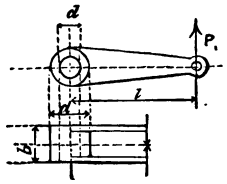
*The Small Levers* (*d*), Fig. 1233.—There are also two of these levers, and they are formed like a fork. The strain upon each of them will be

$$\left[\frac{(P + \frac{1}{2} p) L}{2 l}\right] - \frac{1}{2} p_1 = \left[\frac{(744 + 40) \times 2{\cdot}065}{2 \times 0{\cdot}365}\right] - \frac{9}{2} = 2213 \text{ kilogrammes;}$$

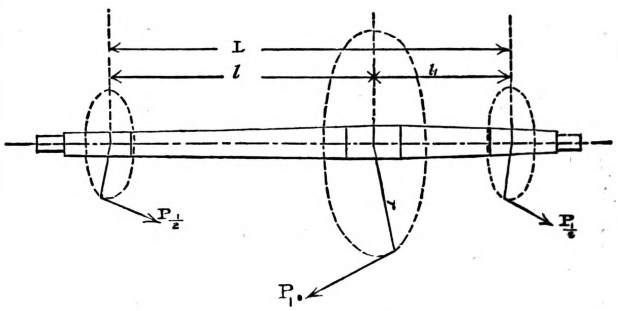
and the equation for equilibrium is thus again $(P + \frac{1}{2} p) l = \frac{RJ}{n}$; or substituting for $\frac{J}{n}$ its corresponding value, we get, for the section at the centre, $(P + \frac{1}{2} p_1) l = \frac{R b (h^3 - h_1^3)}{6 h}$, whence $R = \frac{(P + \frac{1}{2} p_1) 6 h l}{b (h^3 - h_1^3)}$, or $R = \frac{(2213 + 4{\cdot}5) \times 6 \times 0{\cdot}135 \times 0{\cdot}365}{0{\cdot}13 (0{\cdot}135^3 - 0{\cdot}085^3)} = 2633000$ kilogrammes, that is to say, $2^k{\cdot}633$ to the square millimètre; for the section before the centre, $(P + \frac{1}{2} p) l = \frac{R b h^2}{6}$, whence $R = \frac{(P + \frac{1}{2} p_1) \times 6 l}{b h^2}$, or $R = \frac{(2213 + 4{\cdot}5) \times 6 \times 0{\cdot}298}{0{\cdot}03 \times 0{\cdot}13^2} = 7824240$ kilogrammes, or about 8 kilogrammes per square millimètre.

The flexure of these levers will be $f = \frac{(2213 + 4{\cdot}5) \times 4 \times 0{\cdot}365^3}{20000000000 \times 0{\cdot}03 \times 0{\cdot}135^3} = 0^m{\cdot}0003$.

1233.




1234.




*Brake-Shaft* (*e*), Fig. 1234.—The brake-shaft is submitted to two different strains, the one acting by flexure and the other by torsion. The first one is insignificant, and we shall only consider the other.

The moment of torsion for the part $l_1$ is $M = (P + \frac{1}{2} p) r \frac{l}{L}$, which has to be kept in equilibrium by the moment of resistance, $M = \frac{R_1 J}{n} = \frac{R_1 \pi d^3}{16}$. We get, therefore, $(P + \frac{1}{2} p) r \frac{l}{L} = \frac{R_1 \pi d^3}{16}$, whence $R_1 = \frac{(P + \frac{1}{2} p) 16 r l}{\pi d^3 L}$, or $R_1 = \frac{(744 + 40) \times 16 \times 2{\cdot}065 \times 0{\cdot}99}{3{\cdot}14 \times 0{\cdot}085^3 \times 1{\cdot}5} = 8873470$ kilogrammes, or very nearly 9 kilogrammes to the square millimètre.

For the part $l$ of the shaft, the moment of torsion is $M = (P + \frac{1}{2} p) r \frac{l_1}{L}$, therefore, as above, $(P + \frac{1}{2} p) r \frac{l_1}{L} = \frac{R_1 \pi d^3}{16}$, whence $R_1 = \frac{(P + \frac{1}{2} p) 16 r l_1}{\pi d^3 L}$, or

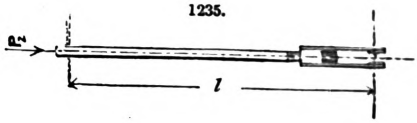
$$R_1 = \frac{(744 + 40) \times 16 \times 2{\cdot}065 \times 0{\cdot}51}{3{\cdot}14 \times 0{\cdot}085^3 \times 1{\cdot}5} = 4571180 \text{ kilogrammes,}$$

say $4^k{\cdot}5$ per square millimètre.

Finally taking G = 6600000000 kilogrammes, we find for the angle of torsion, $t = \frac{(P + \frac{1}{2} p) r l l_1}{J G L} = \frac{(P + \frac{1}{2} p) r l l_1}{0{\cdot}098 d^4 G L}$, or $t = \frac{(744 + 40) \times 2{\cdot}065 \times 0{\cdot}99 \times 0{\cdot}51}{0{\cdot}098 \times 0{\cdot}085^4 \times 6600000000 \times 1{\cdot}5} = 0^\circ{\cdot}01614$, or about $t = 0^\circ\ 0'\ 58''$.

*Coupling or Pressure Rods* (*f*), Fig. 1235.—The pressure upon each brake-block has been previously ascertained to be 4500 kilogrammes.

1235.




The equation of the equilibrium of these rods is $P L^2 = \pi^2 J E$; or substituting for J its value $= \frac{\pi}{64} d^4 = 0{\cdot}0491$, we find $P L^2 = \pi^2 0{\cdot}0491\, d^2 E$, whence $E = \frac{P L^2}{\pi^2 0{\cdot}0491\, d^4}$, or

$$E = \frac{4500 \times 2{\cdot}030}{3{\cdot}14^2 \times 0{\cdot}0491 \times 0{\cdot}055^4} = 2100000000 \text{ kilogrammes.}$$

Now, $i = \frac{P L}{A E} = \frac{P L}{r^2 \pi E}$, or $= \frac{4500 \times 2{\cdot}030}{0{\cdot}0275^2 \times 3{\cdot}14 \times 2100000000} = 0^m{\cdot}0019.$

In conclusion, we give diagrams representing some of the different types of brake frequently used.

Fig. 1236 shows the arrangement of a brake applied to tenders on the Western Railway of France. This brake shows at the same time with what facility eight brake-blocks may be adopted instead of two.

1236.

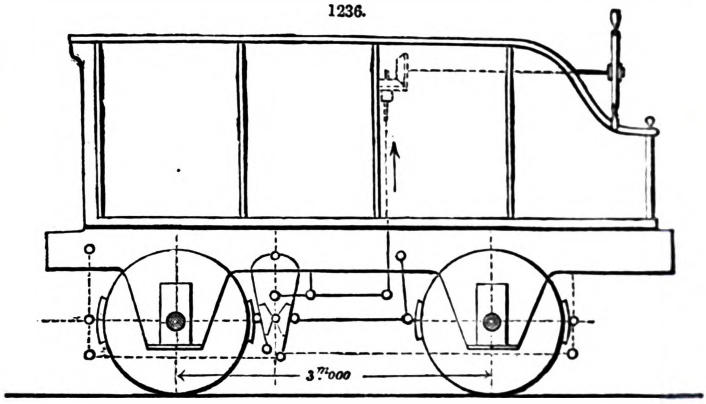



Fig. 1237 shows the brake for the goods wagons on the Eastern Railway of France.

1237.

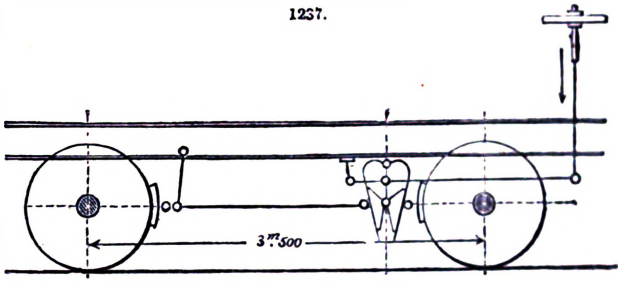
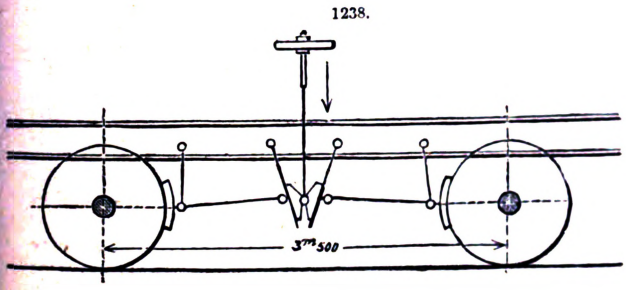



Fig. 1238, brake as adopted on the Northern Railway. A screw with a thread of only 12 millimètres transfers the pressure directly to the wedges.

1238.




1239.

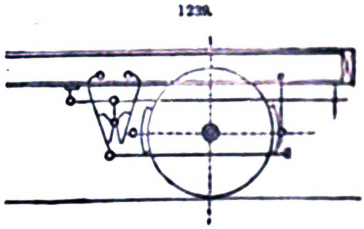


Fig. 1239 shows a hand-brake, acting either upon one wheel only, or upon the two wheels at the same time.

The weights of the brakes of these different systems are :—

1. For the brake of the tender, Fig. 1236, with eight brake-blocks, about 800 or 950 kilogrammes, of which 200 kilogrammes are of cast iron.

2. For the same brake with four blocks only, between 700 and 800 kilogrammes, of which about 150 kilogrammes are of cast iron.

3. For the brake of the goods wagons, as shown in Fig. 1237, between 600 and 650 kilogrammes, of which about 90 kilogrammes are of cast iron, and

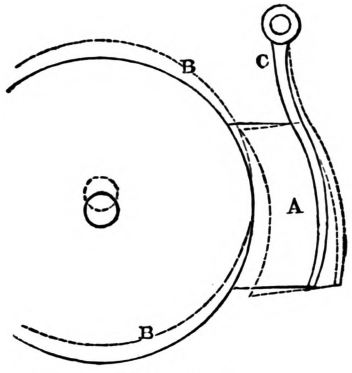
4. For the hand-brake, Fig. 1239, between 240 and 260 kilogrammes, of which 60 kilogrammes are of cast iron.

Numerous brakes have been invented for stopping railway carriages, but nearly all of them act upon the same general principle, and are simply different methods of pressing blocks of wood against the circumference of the wheel, so as to stop its revolution, and cause the tire to slide upon the rails.

If the wheels are all stopped, the friction of the weight of the carriage sliding upon the rails is the whole amount of braking power that can be obtained by any of the plans; and the different methods used to accomplish this add no power for stopping the carriages, but are only different ways of pressing the brake-blocks against the tires, for the purpose of ensuring greater rapidity, certainty, and uniformity of action, reducing the expenses of repairs, and the jarring on the carriage—or to make the brakes self-acting, or worked in combination.

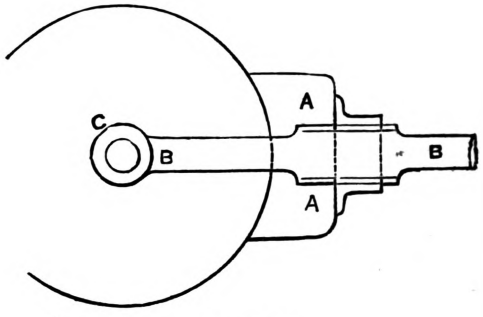
The principal object to be obtained is to have the blocks always pressed square against the wheels, and with a uniform pressure on all the wheels of the same carriage or wagon; unless this is effected there is great difficulty in stopping the wheels, and much straining is caused upon the carriage. In the earlier brakes the block is suspended by a vertical lever from the frame of the carriage or wagon, as shown in Fig. 1240, the block A being shaped to the circle of the wheel; but the varying height of the frame of the carriage, from the variation in the weight of load acting on the springs, causes much inequality in the fitting of the brake-block to the wheel, from the relative level of the brake-block and the wheel being changed, as shown by the dotted line B B; also, the action of the springs is stopped by the pressure of the brake, causing violent jarring and concussions, injurious both to the carriage and the road, and being very annoying to passengers.

1240.



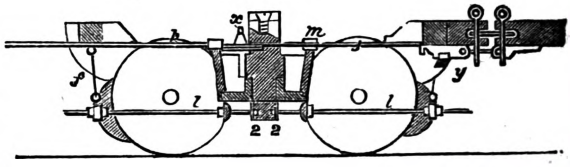

Hanging Brake.

1241.




Sliding Brake.

1242.




The slide-brakes, like those shown in Figs. 1241, 1242, were invented for the purpose of remedying these defects. The relative level of the wheel and the brake-block is preserved unchanged, by the brake-block A sliding horizontally upon a bar B B, which is carried by the axle-boxes at each end, C; a difficulty is experienced, however, in preserving an equal pressure on all the brake-blocks, on account of the unequal wearing of the different bearings.

Davis' brake, Fig. 1242, consists in the arrangement of a series of levers, rods, and springs, which are made to operate upon the brakes; so that when the locomotive ceases to propel the train the brake is applied to the wheels, and released when the locomotive is started. The sliding action is effected by the use of rods *j*, *k*, *l*, *m*, which are thrown into or out of action by the catch *y*. The reciprocating motion is maintained by compound levers acted upon at *x*, and springs placed at *z z*.

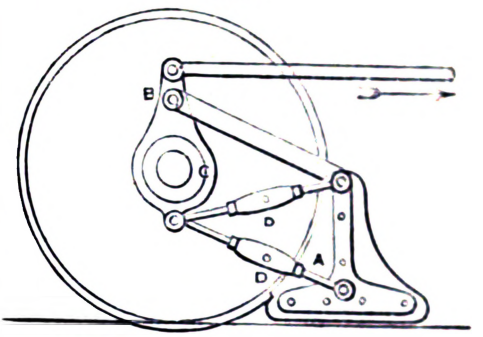
All the above brakes have, however, the serious objection that flat places are worn upon the tires of the wheels, by sliding upon the rails; and the wheels consequently become, to a certain degree, polygonal. Any deviation from the circular form of the wheel becomes a serious source of injury both to the rails and the wheel, from the amount of concussion caused by the great velocity of rolling, and the great weight carried; this also causes increased expense in the wear of the tires and rails.

In Lee's brake, Fig. 1243, the wooden brake-block A is made of a triangular form, and is pressed both against the wheel and the rail by the lever B, which is centred upon the nave of the wheel C, by means of a ring or collar fitting in a circular groove cut round the nave; the rubbing

face of the wood block is shod with copper or iron. The connecting-rods D D have adjusting-screws, to preserve the relative position of the brake-block A and the wheel, as the surface of the block wears away

The mechanical arrangement of this brake, it will be perceived, does not admit of sufficient pressure being applied against the wheel and the rail to form an efficient brake; but even if the pressure were sufficient to stop the wheel, the same objection would still apply as in the ordinary brake, namely, flat places would be worn on the wheel. This brake was tried on one or two railways, but has not come into use.

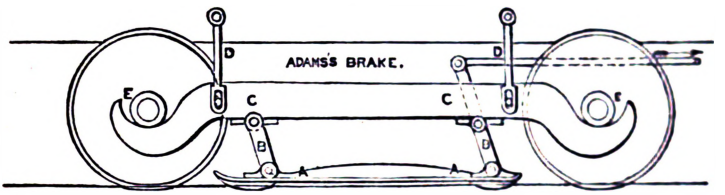
1243.




Lee's Brake.

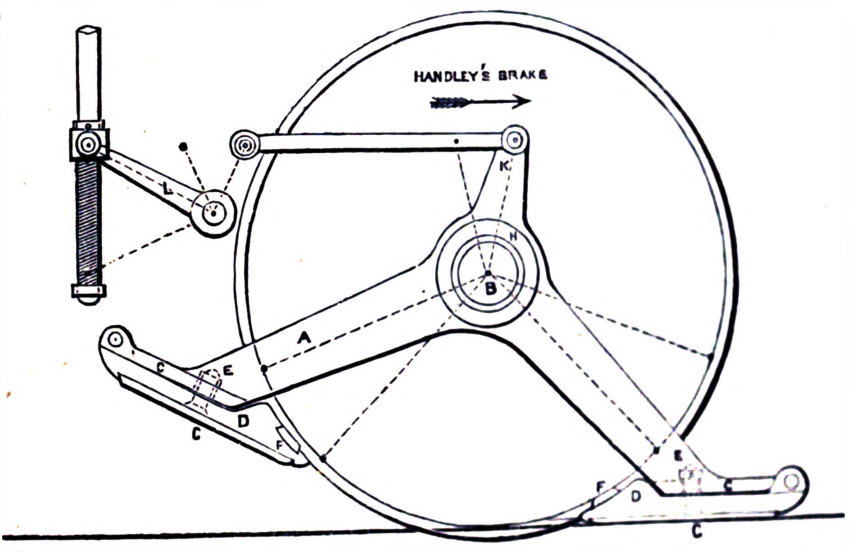
Adams's brake, Fig. 1244, consists of a sledge A A sliding upon the rails, upon which the whole weight of the carriage is thrown by lifting the wheels off the rails. The sledge A A is a long piece of iron, with a flange at each end to guide it on the rails, and is suspended by two links B B from the iron bar C C, which is supported by the links D D, and bears against the under-side of the axle-box at each end, E E; the links B B are in the form of a parallel rule, and when they are straightened by the action of the lever, the sledge A A is pressed upon the rails, and lifts up the wheels from their bearing on them. This brake saves the wheels from being worn flat; but it requires great power to put the whole weight of the carriage upon the sledge, and is consequently slow in action; and there is also an objection to it in having the wheels hanging without any support when the brake is in action. It has not come into use in England, but several brakes on this principle have been used in Belgium for some time previously.

1244.




Handley's brake, Fig. 1245. This brake is on the same principle as the ordinary skid used on common roads; the two iron arms A A are carried by the axle B, upon which a brass ring H is fitted,

1245.




turning round the axle; and at the end of these arms are fixed the shoes or skids C C, one of which is made to pass under the wheel, whichever way the carriage is running, raising it from the rails by turning the lever round upon the axle. The shoe is made the breadth of the tread of the wheel, without any flange, and the wheel is lifted only about ⅛ of an in. on the average, so that the flange

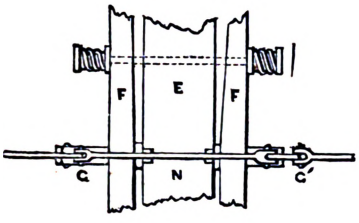
of the wheel continues as efficient and secure a guide upon the rails as in the ordinary case of a wheel stopped from revolving by the pressure of a brake-block. The shoe is made in two pieces: the upper one, C, is forged on to the arm A, and the lower piece, D, which forms the skid, is hinged to it at the end. The object of this construction is to prevent the shoe from touching the wheel until it is required to be put in action; the joint opens about $\frac{1}{4}$ of an in., and the shoe falls away from the wheel when it is lifted, being stopped by the bolt E, which limits the extent of its opening; and round this bolt is placed a short spiral spring, to keep the joint open, and prevent it from shaking when the carriage is running.

The wear of the shoe is provided for by inserting two small dove-tailed pieces, F and G, at the points where the wear takes place; these pieces are slightly tapered, and are driven into their places from the inner side, being burred or riveted on the opposite side, where they remain firmly fixed, having no tendency to work loose. The lower piece is of wrought iron, which is found to answer best for the purpose; the upper one, F, which carries the wheel, is of cast iron. It has very little wear upon it, but is changed occasionally for a piece of greater thickness, to allow for the wear of the shoe-plate G, and preserve the total thickness of the shoe, within very little variation, so as to prevent much difference in the height that the wheel is lifted from the rails.

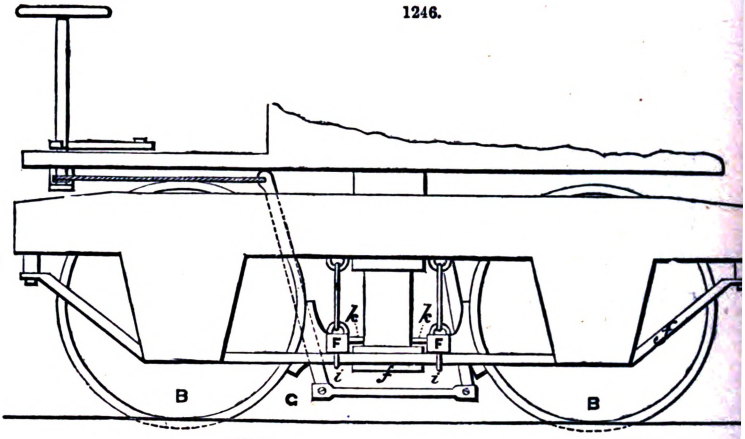
This brake is easily and quickly applied, by means of the lever L acting on the upper arm of the brake K, as the carriage runs upon the shoe when it is pressed under the wheel. The ordinary brake-screw, lever, and cross-shaft, are available for working this brake.

The brake, Figs. 1246, 1247, invented by D. Goodnow, of Albany, U.S., is very ingeniously arranged. The object the inventor had in view was to obviate those accidents that arise from applying the brakes of a railroad car to the outer sides of the four wheels of the truck, by a compact arrangement of the brakes in the centre between the wheels of the trucks, thereby exposing them to less danger of breaking, or their parts becoming detached. This arrangement further consists in so constructing the brake-bars, in combination with the jaw-braces of the trucks, that in case the bars are broken they cannot fall to the track and obstruct the wheels; further, in operating the two brakes conjointly by the direct endwise thrust of a short connecting-bar, both brake-blocks are made to act upon the wheels simultaneously.

1247.




1246.




The brake-bars F, F, Fig. 1246, extend beyond the jaw-braces *f*, *f*, to which they are connected by the yokes *i*, *i*. In Fig. 1247, E represents the position of the plank or *hang-frame* in relation to the brake-bars F, F, and the guide and safety rods *k*, *k*. How the brake-bars F, F, lever G, G', connecting-bar N, car-bearing E, and truck wheels B, B, are combined and arranged, is clearly shown in Figs. 1246, 1247.

Now we propose to place the subject of this article in a clear light, and in a plain practical form; since it has been handled in an erroneous, an obscure, or a slovenly manner, by most mechanical writers and experimentalists.

A carriage on a level railroad only requires a pressure of about $\frac{1}{300}$ part of the moving weight to give it motion, or from 4 to 8 lbs. a ton. The fraction $\frac{1}{300}$ is called the coefficient of friction; as these coefficients become smaller, the rubbing surfaces become smoother. All constant resistances may be expressed in a similar manner.

The work of every machine is consumed by the work done, or by the useful work, together with the useless work, or the work destroyed by the friction of the parts of the machine. We will here explain one of the most beautiful laws of motion: When the work applied exceeds the work consumed, the redundant work goes to increase the speed of the parts of the machine, and at the same time, like the fly-wheel, acts as a reservoir of work. *This acceleration goes on increasing until the work of the resistances + the useful work = the work applied; and then the motion of the machine becomes uniform.*

For example, in a railroad engine and train, at first the work of the engine exceeds the work of the resistances, and hence the speed of the engine goes on increasing; but, as the speed increases, the work of the resistances also increases, so that ultimately the engine attains a nearly uniform motion, which is called the greatest or maximum speed, and then the work destroyed by the resistances will be exactly equal to the work applied by the moving power. A few simple examples will make this law clear.

*Ques.*—Required the effective horse-power of a locomotive engine which moves at a steady speed of 23 miles an hour upon a level rail, the weight of the train being 100 tons, and the constant resistances amounting to 5 lbs. a ton?

Put $x$ = the required horse-power.

The work of the engine a minute = $x \times 33000$ units of work.

The resistance = $5 \times 100 = 500$ lbs.

The distance moved a minute = $\frac{23 \times 5280}{60} = 2024$ ft.; or $33\frac{11}{15}$ ft. a second.

Work to overcome the constant resistances, in a minute = $2024 \times 500 = 1012000$ units of work.

But as the speed of the train is uniform, the work of the resistances will be equal to the effective work of the engine:

$$\therefore \quad x \times 33000 = 1012000 \qquad \therefore \quad x = \frac{1012000}{33000} = 30{\cdot}7 \text{ horse-power.}$$

Now suppose the uniform resistances and the power of the locomotive to be removed, then the train would move for a short time with a velocity ($v$) of $33\frac{11}{15}$ ft. a second, but would come to rest after passing over a space ($s$) of 7900·888 ft., when opposed by the constant resistance ($f$) of 500 lbs. on the level rails.

If the constant resistance ($f$) be 1000 lbs., this train would come to rest when $s$ = 3950·444 ft. When $f$ = 2000 lbs., then $s$ = 1975·222 ft., and so on. The units of work conserved in a body weighing W lbs., moving with a velocity of $v$ ft. a second, is equal to $\frac{W}{g} \times \frac{v^2}{2}$. See Byrne's 'Essential Elements of Practical Mechanics,' p. 97. In this case $g$ = 32·2 lbs., the supposed weight of a unit of mass. $\frac{W}{g}$ is termed the mass of a body whose weight is W lbs.

Whence $\frac{W}{g} \times \frac{v^2}{2} = \frac{100 \text{ tons} \times 2240}{32{\cdot}2} \times \frac{(33\frac{11}{15})^2}{2} = 3950444$ units of work;

and $fs = 500 \times 7900{\cdot}888 = 3950444$,
or $fs = 1000 \times 3950{\cdot}444 = 3950444$,
or $fs = 2000 \times 1975{\cdot}222 = 3950444$, and so on.

*Ques.*—What is the rate in miles an hour of a train of 80 tons, drawn by an engine of 70 horse-power, when the constant resistances amount to 8 lbs. a ton?

Call $x$ the uniform speed in miles an hour.

Work used in moving the train $x$ miles = $80 \times 8 \times 5280 \times x$; this is the work done by the engine in an hour. But the work done by the engine in an hour will also be expressed by

$$33000 \times 70 \times 60;$$

$$\therefore \quad 33000 \times 70 \times 60 = 80 \times 8 \times 5280 \times x; \qquad \therefore \quad x = \frac{33000 \times 70 \times 60}{80 \times 8 \times 5280} = 48{\cdot}02 \text{ miles.}$$

When the propelling power ceases to act, and a constant resistance of 11200 lbs. ($f$) (five tons) is applied, then this train will come to rest after passing over a space ($s$) of 894 ft. Since the uniform velocity ($v$) in this case is 60 ft. a second,

$$\therefore \quad \frac{W}{g} \times \frac{v^2}{2} = \frac{80 \times 2240}{32{\cdot}2} \times \frac{(60)^2}{2} = 10017392 \text{ units of work;}$$

$$\text{but, } f \times s = 11200 \times 894 = 10012800 \text{ units of work.}$$

*Ques.*—An engine of 48 horse-power moves with a maximum speed of 33 miles an hour on a level rail; required the gross load of the train, when the constant resistances amount to 6 lbs. a ton?

Let $x$ be the gross weight of the train in tons; then the work consumed an hour in moving the train = $x \times 6 \times 33 \times 5280$.

Work of the engine an hour = $48 \times 33000 \times 60$.

When the speed is uniform or at its maximum, $x \times 6 \times 33 \times 5280 = 48 \times 33000 \times 60$;

$$\therefore \quad x = \frac{48 \times 33000 \times 60}{6 \times 33 \times 5280} = 90\tfrac{10}{11} \text{ tons.}$$

In this example $fs$ = 7407307 units of work = $\frac{W}{g} \times \frac{v^2}{2} = \frac{1000}{11} \times \frac{2240}{32{\cdot}2} \times \frac{(48{\cdot}4)^2}{2}$. Hence a constant resistance ($f$) of 3000 lbs. will bring this train to rest after it has passed over a space ($s$) of 2469·102 ft., for $fs = 3000 \times 2469{\cdot}102 = 7407307$ units of work.

*Ques.*—In what time will an engine of 66 horse-power, moving a train of 200 tons, complete a journey of 100 miles, friction and other constant resistances amounting to 5 lbs. a ton, rails horizontal?

Work expended in moving the train 100 miles = $100 \times 5280 \times 200 \times 5 = 528000000$.

Work of the engine an hour = $33000 \times 66 \times 60 = 130680000$;

$$\frac{528000000}{130680000} = 4{\cdot}04 \text{ hours.}$$

In this case $v$ = 36·3 ft. a second, and $\frac{W}{g} = \frac{200 \times 2240}{32{\cdot}2}$;

$$\therefore \quad fs = \frac{W}{g} \times \frac{v^2}{2} = 9166539 \text{ units of work.}$$

This work is conserved in the train, and exists in the train independent of the power of the engine and of the opposing resistances.

The following summary of experiments made to test the retarding power of different railway

brakes is taken, with some alterations and explanations, from a paper by W. Fairbairn, printed in the 'Proceedings of the Institution of Civil Engineers,' vol. xix. Suppose a train impelled by a locomotive engine until it attains a uniform velocity $v$ in feet a second; that then the brakes are applied, and the train brought to a stand after passing a distance $s$ in feet: it is required to find a measure of the force by which the momentum has been destroyed. Inasmuch as the brakes act by friction, which may be considered, with sufficient accuracy, to be uniform throughout the operation of braking, the train may be assumed to be stopped by a uniformly retarding force acting through the space $s$. If the retarding force in this case is called $f$, consisting mainly of the friction of the braked wheels, and, for simplicity, including also the friction of the axles, resistance of the air, and other constant resistances, then

$$f = \frac{v^2}{2s} \qquad [1]$$

But supposing, as is generally the case, that the retarding force of the brakes is proportional to a part of the weight of the train only, that is, that the retarding force generated varies as the weight on the rubbing surfaces, and supposing the brakes to be applied to a few carriages only, putting $w$ for the weight of the brake carriages in tons, and W for the weight of the train, then

$$f_1 = \frac{W v^2}{2 w s} \qquad [2]$$

which gives the retarding force to each unit of mass of the brake carriages.

It will be convenient to reduce this force to terms of weight instead of mass. Call $f_2$ the retarding force in pounds a ton weight of the brake carriages, then

$$f_2 = f_1 \times \frac{2240}{32{\cdot}19} = 69{\cdot}587\, f_1; \qquad [3]$$

that is, $f_2 s = \dfrac{\frac{W}{w} \times 2244}{g} \times \dfrac{v^2}{2}$ = the units of work done in resisting the constant force ($f_2$) through a space ($s$); $\dfrac{g f_2}{2240} s = \dfrac{W}{w} \times \dfrac{v^2}{2} = f_1 s$, and $\dfrac{w}{W} \times \dfrac{g f_2}{2240} s = \dfrac{v^2}{2} = fs$. $v$ and $s$ are variables, but W, $w$, $g$, are constants.

Again, supposing that, instead of being on a level line, the brakes are applied on an incline. Then the action of gravity will cause the train to go farther, if it is descending the incline, or to stop sooner, if ascending, than if the line was level; and gravity is a uniformly accelerating or retarding force, as the friction of the carriages. Hence the net result in distance and velocity of a train stopped on an incline may be supposed to arise from two forces: $f$, a retarding force dependent on the friction of the braked wheels; and $\phi$, a retarding or accelerating force dependent on gravity, and assisting or opposing the action of $f$, according as the incline rises or falls; thence

$$f \pm \phi = \frac{v^2}{2s} \qquad [4]$$

Now, the value of $\phi$ in terms of the inclination $\theta$ of the plane to the horizon is known, for if $g$ be the velocity generated by the gravity in one second, $\phi = g \sin. \theta$; or putting $z$ for the vertical height fallen through by the train between the time of applying the brakes and stopping the train, $\phi = g \dfrac{z}{s}$;

$$\therefore \quad f = \frac{v^2}{2s} \pm g \sin. \theta = \frac{v^2}{2s} \pm g \frac{z}{s}$$

$$\text{or,} \quad f = \frac{\frac{1}{2} v^2 \pm g z}{s} \qquad [5]$$

$$f_1 = \frac{W}{w} \times \frac{\frac{1}{2} v^2 \pm g z}{s} \qquad [6]$$

$$f_2 = \frac{2240}{g} \times \frac{\frac{1}{2} v^2 \pm g z}{s} = 69{\cdot}587\, f_1 \qquad [7]$$

where the + or − sign is to be adopted, according as the gradient falls or rises.

In the increase of the brake-power of trains, the principles hitherto most successfully employed have been,—first, the use of steam acting direct on the brakes; secondly, the connection of several of the ordinary form of brakes, so as to unite them under the control of a single brakesman; and thirdly, the introduction of brake apparatus connected with the buffers, so as to make the momentum of the train itself available in generating a retarding force.

M'Connell's brake, which is applicable only to the engine, consists of two wrought-iron sledges, each 48 in. in length and 4 in. in breadth, and turned up at the ends. These sledges are suspended from the lower side of the fire-box, between the driving and the trailing wheels of the engine. The pressure is placed on them by admitting steam from the boiler into two cylinders, each 9 in. in diameter, placed horizontally, one on each side of the fire-box, above the sledges, and forcing these latter down upon the rails by means of an elbow-joint. The pressure can be applied to either side of the pistons in the cylinders, according as the brakes have to be raised or depressed. The pressure of the sledges upon the rails, calculated from the pressure of the steam in Yolland's trials, would amount to about 6 tons. On the weighing machine, however, the actual pressure was found to vary from 4 tons to 9 tons, or a mean of about 7 tons; and these anomalies Yolland was unbale to solve. The principal advantage of this brake appears to be that it is immediately applied without exertion, and is under the control of the engine-driver, who in

most cases is the first to perceive any obstruction on the line. It will be seen, however, that although efficiently generated, the amount of retardation caused by this brake is comparatively small, and, as Colonel Yolland concludes, insufficient to prevent collision in those cases in which its use would be specially desirable.

Newall's and Fay's brakes, which in their present condition are identical in principle, are distinguished from other brakes by this—that two or more carriages, or, if necessary, the whole train, are fitted with brake-blocks, all of which are brought under the direction of one guard by means of a longitudinal shaft, which transfers the motion of the guard's wheel to the brakes throughout the whole length of the train. In this way a great increase of retarding power may be obtained proportional to the weight of the carriages to which brakes are applied, and with this further advantage, that the retarding force is distributed equally throughout the train, instead of being accumulated at either end, and thus the shock upon the wheels and axles is much diminished. Newall and Fay have also adopted a partially self-acting apparatus of springs, by means of which the brakes are applied throughout the length of the train on the simple release of a catch by a guard.

In Newall's brake, the motion of the guard's or the engine-driver's wheel, since either or both of these may have the control of the brakes, is transferred, through the medium of a short vertical shaft in the van or tender, to the longitudinal shaft placed beneath the carriages of the train, by a pair of bevel-wheels, or by a spur-wheel and pinion. The longitudinal shaft passes either beneath the centre or at one side of the carriage, under the framework; and it is connected by simple, but very effective, jointed couplings between each pair of carriages, so as to permit the free action of the buffers, and the rise and fall of the carriages with the inequalities of the line. Near to the middle of the carriage a bevel-wheel is fixed on the longitudinal shaft, which is toothed into a similar one on a short cross-shaft, carrying also a spur-pinion geared into a horizontal rack. Thus, on revolving the guard's wheel, this rack is drawn back, withdrawing at the same time the principal arm of the rocking-shaft, at the centre of the carriage, and compressing a spring placed on the other side, to both of which the rack is attached by a simple connecting-rod. In this position the brake-blocks are off the wheels, and the brake is ready for use. If the bevel-wheel or pinion in the guard's van, or tender, is now released, or lifted out of gear by a lever or treadle, the springs throughout the train will force back the arm of the rocking-shaft, which carries the levers that press the brake-blocks on the wheels. If it is required to put on the brakes harder, and to skid the wheels, the treadle is again released by the guard, and the pressure increased by revolving the wheel in the ordinary way. In other words, Newall and Fay provide a number of springs, or in some cases weights, under each carriage, in which is stored up, ready for instantaneous use, a stock of brake-power, derived from the one guard acting through a longitudinal shaft, communicating with every brake by means of an arrangement of spur-wheels and pinions. From this it will be seen that on any emergency the retarding force may be instantly employed by simply releasing a catch, which permits the brake-blocks to be forced upon the wheels by the springs throughout the train.

In the class of brakes in which greater retarding power is obtained by increasing the number of braked carriages and combining their action, the systems just described appear the best and most comprehensive hitherto adopted. Fairbairn mentions that he received from E. W. Watkin the details of some experiments on an auxiliary brake carriage designed upon a different plan. In this case, an ordinary brake arrangement is employed, with a double elbow-joint, to which a long vertical lever is attached, moving in an arc against the side of the van. A rope from the end of this lever is conveyed to the tender, or the guard's van, and is attached to a drum on the axis of the ordinary guard's wheel. Hence, when the guard or the fireman revolves his wheel to put on his own brake, the rope coils upon the drum, drawing back the lever, and thus putting on the auxiliary brakes at the same time.

Belonging to the third class of brakes before enumerated, in which the momentum of the train itself is employed in generating the retarding force, there is only the brake of M. Guerin, which is entirely self-acting, and is brought into use by the recoil of the buffer-rods, when, by the application of the tender-brake, a retardation has been caused in front. Yolland thus describes this brake:—The buffer-rods at the after end of the carriage abut against a spring that extends across its width; one buffer-rod acting against each end of the spring. This spring, instead of being fixed against the under-framing of the carriage or the brake-van, is movable in a groove. On one side the centre of the spring is secured to the draw-bar, and on the other it is attached to the arm of a short lever, fixed almost vertically over the rocking-shaft; so that when the buffers are pressed in by the sudden check to the velocity—caused by shutting off the steam, by the application of the tender-brake in front, and by the momentum of the train in the rear—the buffer-spring is carried forcibly against the lever, the rocking-shaft is turned, and the brake-blocks are forced against the peripheries of the wheels. The brakes are prevented from being put on when a train is required to be shunted, by a cross-head or stop. But this provision interferes with the application of the brakes when the train is in motion at a low velocity. For such a speed it is assumed the tender-brake will be sufficient.

These are the brakes upon which the experiments were made, and the results tabulated and classified.

*Newall's and Fay's Continuous Brakes.*—In carrying out the views of the Directors of the Lancashire and Yorkshire Railway, Fairbairn arranged, in the first place, for a series of experiments on the Oldham incline, where two similar trains of carriages, one fitted throughout with Newall's and the other with Fay's brakes, were started alternately. After passing over a measured distance by the action of gravity, the brakes were applied, and the distance within which the trains were respectively brought up was carefully ascertained, as giving the measure of the brake-power of the trains. Each train consisted of three weighted carriages, and they were started by simply releasing a stop. Having descended, by gravity, a previously-measured distance,

with a uniformly accelerated velocity, they passed over a *fog-signal*, which gave notice to the guard to put on the brakes. Then the train having been brought to a stand, the distance from the point at which the train stopped to the *fog-signal* was measured back, and the train was dragged up the incline for another trial. Unfortunately, the day on which these experiments were made proved misty and foggy, with rain at intervals, so that the rails were in the worst condition for facilitating the stopping of the trains. The significance of this fact will be seen on comparing these results with later ones obtained in dry weather.

TABLE I.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES ON THE OLDHAM INCLINE, FEBRUARY 6, 1859.

Weather foggy and wet; gradient falling 1 in 27; weight of trains, 26 tons 10 cwt. each; no engine attached.

| FAY'S FLAP-BRAKES. | | | | | NEWALL'S SLIDE-BRAKES. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running. | | Distance Run. | | No. | Time of Running. | | Distance Run. | |
| | Before Braking. | After Braking. | Before Braking. | After Braking. | | Before Braking. | After Braking. | Before Braking. | After Braking. |
| | seconds. | seconds. | yards. | yards. | | seconds. | seconds. | yards. | yards. |
| 1 | 35 | .. | 150 | 153 | 1 | 35 | 14 | 150 | 281 |
| 2 | 40 | 13 | 200 | 250 | 2 | 40 | 16 | 200 | 336 |
| 3 | 48 | 14 | 300 | 360 | 3 | 48 | 17 | 300 | 459 |
| 4 | 58 | 15 | 400 | 499 | 4 | 56 | 25 | 400 | 608 |
| 5 | 59 | 12 | 400 | 326 | 5 | 56 | 14 | 400 | 371 |
| 6 | 62 | 25 | 500 | 739 | 6 | 62 | 19 | 500 | 663 |
| 7 | 72 | 17 | 600 | 575 | 7 | 68 | 17 | 600 | 545 |
| .. | .. | .. | .. | .. | 8 | 63 | 32 | 500 | 798 |

In experiment No. 8 the self-acting part of the brake only was employed.

In these experiments the whole of the wheels were sledged, or skidded, before the train was stopped. The self-acting arrangement of springs was fitted to Newall's carriage alone. In the later experiments it was adopted also by Fay.

Taking the mean of the number of seconds required in braking each train, in experiments Nos. 2, 3, 4, 5, 6, and 7, which were made under precisely corresponding circumstances in the case of each brake, and at similar velocities, it is found that the train was brought to a stand:—By Newall's brake, in 2·16 seconds; by Fay's brake, in 19·2 seconds; or about 2½ seconds of time in favour of Fay's.

It will, however, be advisable to ascertain the precise value of the retarding force in each case by the formulæ already given. To effect this, the initial velocity of the train at the instant of applying the brakes must first be ascertained. For this purpose the least objectionable formula and at the same time the most simple is

$$v = \frac{2s}{t} \qquad [8]$$

for taking the mean velocity between $o$, and $v = \frac{v}{2}$ and $\frac{v}{2}$ multiplied by $t$ second = the distance $s$; $\therefore \frac{v}{2} \times t = s$; where $v$ is the velocity in feet per second; $s$ is the distance run, in feet; and $t$ is the time of running, in seconds. From this formula the following initial velocities of the train, in feet per second, in the preceding experiments, are obtained:—

| No. | Fay. | Newall. | No. | Fay. | Newall. |
|---|---|---|---|---|---|
| 1 .. | 25·71 | 25·71 | 5 .. | 40·66 | 42·85 |
| 2 .. | 30· | 30· | 6 .. | 48·38 | 48·38 |
| 3 .. | 37·50 | 37·50 | 7 .. | 50· | 52·94 |
| 4 .. | 41·37 | 42·85 | 8 .. | — | 47·61 |

Hence, by equation [6], since in this case $\frac{W}{w} = \frac{26·5}{26·5} = 1$, and therefore $f = f_1$, and $f_1 = \frac{\frac{1}{2}v^2 + g\,z}{s}$, the relative values of each description of brake, and their comparative efficiency in each trial, may be derived. The retarding force of each brake is found to be as follows:—

| No. | Fay. | | Newall. | |
|---|---|---|---|---|
| 1 .. .. | 1·9115 | | 1·3246 | |
| 2 .. .. | 1·7922 | | 1·6388 | |
| 3 .. .. | 1·8432 | | 1·7030 | |
| 4 .. .. | 1·7645 | Mean 1·8538. | 1·6946 | Mean 1·7436. |
| 5 .. .. | 2·0280 | | 2·0152 | |
| 6 .. .. | 1·7205 | | 1·7811 | |
| 7 .. .. | 1·9167 | | 2·0480 | |

Giving, as in the previous comparison, the advantage to Fay, in the proportion of 1·8538 to 1·7436, or as 1051 to 1000. The entire agreement of the results among themselves, and with the preceding comparison derived from the time, is sufficient evidence of the practical accuracy of the formula of reduction. The brakes stand, in these experiments, very nearly on an equality of merit.

The experiments in the next Table were made at Southport, upon a line more nearly level. The speed was obtained by means of a locomotive engine, which was detached, at the instant of applying the brakes, by a slip-coupling. The velocity, which was maintained uniform over the last half-mile, was measured by noting the time required to pass two fog-signals, placed half a mile apart. The brakes, in every trial, were applied almost instantaneously, after the report of the second fog-signal, and the distance was measured after the train had come to a state of rest.

TABLE II.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, JANUARY 7, 1859.

Weather fine and frosty; gradient rising 1 in 485; weight of trains, 26 tons 10 cwt. each.

| FAY. | | | | | NEWALL. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet, a Second. | Distance of Pulling up, in Yards. | No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. |
| 1 | 42 | 42·85 | 62·86 | 184 | 1 | 31 | 58·06 | 85·16 | 240 |
| 2 | 40 | 45· | 66· | 206 | 2 | 30 | 60· | 88· | Lost, |
| 3 | 34 | 52·94 | 77·65 | 272 | as also another experiment. | | | | |
| 4 | 31½ | 37·14 | 83·81 | 313 | | | | | |
| 5 | 30 | 60· | 88· | 329 | Engine alone | 30 | 60· | 88· | 960 |

The second experiment with Newall's brakes failed, in consequence of the guard applying the brakes too soon; and a third was lost from the fracture of the slip-coupling.

When these results are reduced by the same formula, the following values of $f_1$, representing the efficiency, or retarding force of each brake, are obtained:—

| No. | Fay. | Newall. |
|---|---|---|
| 1 .. .. | 3·5125 | 4·97 |
| 2 .. .. | 3·4579 | |
| 3 .. .. | 3·6274 | Mean 3·6256. |
| 4 .. .. | 3·6738 | |
| 5 .. .. | 3·8566 | |

These experiments give a superiority in favour of Newall's brakes, in the proportion of 4·97 to 3·6256, or as 1378 to 1000.

The value of the retarding force, $f$, for the tender-brake, derived from the last experiment, is 1·2791, and reducing this, in proportion of the weight of the tender to the weight of the engine and tender, it becomes $f_1 = 4·3455$.

At this period, Fay requested permission to attach a self-acting apparatus to his brakes, as he considered they were not fairly matched against those of Newall, when applied by hand. The experiments were, therefore, postponed for two months, to enable Fay to effect this alteration. They were again resumed on the 14th of April, 1859.

TABLE III.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, APRIL 14, 1859.

Weather, dry during the first, with a slight shower during the remaining experiments; gradient falling 1 in 3453; weight of trains, 27 tons 6 cwt.

| FAY. | | | | | NEWALL. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. | No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. |
| 1 | 56½* | 31·8 | 46·7 | 121¾ | 1 | 58 | 31· | 45·5 | 101 |
| 2 | 53¾ | 33·4 | 49·1 | 124 | .. | .. | .. | .. | .. |

* Engine attached and tender-brake applied.

Reducing the results, as before: $f_1 = 3·2329$ with Fay's brake; $f_1 = 3·4161$ with Newall's brake; $f_1 = 2·9956$ with Fay's brake and tender-brake.

Here the superiority lies with Newall, in the ratio of 1056 to 1000. The experiment with the engine attached, when reduced in the ratio of the weight of the train to the weight on the wheels braked, gives $f_1 = 4·84$.

It will be observed that as the value of the retarding force of the brakes is here obtained in

terms of the coefficient of friction, for the rubbing surfaces, the efficiency of the brake varies with the condition of the weather. Thus the mean of the Oldham experiments gave a retarding force of 1·7987 ft. per second; the mean of the first experiments at Southport gave 4·2978, and the mean of the second 3·3245. On each day the experiments were consistent with one another, but they differed widely, on different days, from the change in the condition of the rubbing surfaces. At Oldham, the experiments were made with the rails in a greasy condition, from fog; at Southport, in the later of the two trials, with the rails slightly wet, and in the earlier, with rails dry, and in the best condition for braking. This is in accordance with the experiments of Morin on the friction of iron on iron, in which it was found that the coefficient of friction varied from 0·05 to 0·3, according as the surfaces were greasy, wet, or dry. This consideration must be borne in mind in estimating the results; and together with some improvements in the adjustment of the brakes, and the introduction of increased power, from time to time, will explain the discrepancies which may be found, on comparing the results obtained at different periods of the trials.

The remaining experiments upon the self-acting brakes were all made under uniform and favourable conditions; the weather was fine, and the wind blew each day from the west or the north-west. The results, also, are uniform for these days, and there can, therefore, be no error in placing these experiments in the same Tables, and averaging them together This classification will, therefore, be adopted as more convenient, and they will be arranged under the following heads:—

1. Experiments on the friction of the carriages.
2. Experiments with slide-brakes, with the engine detached.
3. Experiments with flap-brakes, with the engine detached.
4. Experiments with the engine attached to the train.

*Experiments on the Friction of the Carriages.*—These experiments were made by running the train, as before, past two fog-signals, half a mile apart, to obtain the velocity, detaching the engine at the second fog-signal, and allowing the train gradually to come to rest.

TABLE IV.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, JUNE 2, 1859.

| | Time of Running ½ Mile, in Seconds. | Speed, in Miles an Hour. | Distance run, after applying Brakes, in Yards. | Time of Running, after applying Brakes, in Seconds. | Height fallen through by Train from inclination of Line, in Feet. |
|---|---|---|---|---|---|
| Fay .. .. .. | 40· | 45· | 4840 | 430 | 7·06 |
| Newall .. .. | 44·5 | 40·45 | 6380 | 780 | 13·91 |

Reducing as before, the normal friction of the carriages, $f = f_1$, is found to be,—Fay, 0·16565; Newall, 0·10961: and therefore $f_2$, or the friction per ton weight of the carriages, is,—Fay, 11·527 lbs.; Newall, 7·627 lbs.; mean, 9·577 lbs.

This shows that there is a considerable difference between the friction of the two sets of carriages; and a small correction should therefore be made, in the reductions of the experiments on brakes, in favour of Newall, if perfect accuracy were required. The correction, however, does not exceed one-sixtieth of the retarding force of the brakes, and may be neglected without appreciable error. These experiments were made with carriages fitted with slide-brakes, and the friction of those with flap-brakes was not determined.

In an experiment recorded in Yolland's Report, the friction, derived in the same way, for a train of carriages fitted with Newall's brakes, and attached to an engine and tender, amounted to 11·4 lbs. per ton. This, when allowance is made for the greater friction of the engine, nearly agrees with Fairbairn's results.

*Experiments with Slide-Brakes, with the Engine detached from the Train.*—The following experiments were made between the Birkdale and Amsdale stations, on the line between Liverpool and Southport. As before, the engine was attached by a slip-coupling to the train. At the quarter and the three-quarter mile posts from Amsdale, fog-signals were placed, and the time of passing between these, being accurately observed by stop-watches, gave the average speed of the train. At the second fog-signal, the slip-coupling was unfastened, and the brakes applied, instantly on hearing the report. The assistant, Unwin, and other persons, were placed in the guard's van, to prevent the premature application of the brakes; and others on the engine with the driver, to see that there was no change of velocity in passing over the half-mile in which the speed was observed. The line where these experiments took place rose, for 500 ft. from the first fog-signal, with a gradient of 1 in 1087, and then fell for upwards of a mile, with a gradient of 1 in 3543, a fall so slight, in the short space in which the trains were brought to rest, that it cannot appreciably affect the results; and in the reductions the line has been considered as level.

The trains with which these experiments were made consisted of three heavily-weighted carriages, each with brakes to every carriage, except in the two last experiments, when, in consequence of an accident to one of Newall's carriages, the trains were reduced to two. The carriages were loaded with iron rail-chairs, so as to weigh 9 tons 2 cwt. each.

The power of these continuous brakes was well exemplified upon the 18th May, when Fay's guard inadvertently applied the brakes whilst the train was running at a comparatively slow velocity; the strong coupling-hook which united the tender to the guard's van was instantly snapped, and the train brought to a stand.

TABLE V.—EXPERIMENTS WITH NEWALL'S AND FAY'S SLIDE-BRAKES AT SOUTHPORT, MAY, 1859.

| NEWALL. | | | | | FAY. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. | No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. |
| 2 | 55 | 32·72 | 48· | 56⅔ | 2 | 51 | 35·29 | 51·76 | 56 |
| 4 | 49 | 36·73 | 53·87 | 77 | 4 | 41 | 43·9 | 64·39 | 98 |
| 6 | 41½ | failed | .. | .. | 5 | 36 | 50· | 73·33 | 129 |
| 7 | 41 | 43·9 | 64·39 | 136 | 6 | 33 | 54·54 | 80· | 144 |
| 8 | 39 | 46·15 | 67·69 | 140⅔ | 7† | 33 | 54·54 | 80· | 161⅓ |
| 9 | 34 | 52·94 | 77·64 | 205⅓ | 9‡ | 47½ | 37·89 | 55·58 | 97 |
| 10* | 33 | 54·54 | 80· | 192 | 10‡ | 30 | 60· | 88· | 204⅓ |
| 11† | 38 | 47·37 | 69·47 | 260⅓ | 11‡ | 30 | 60· | 88· | 214 |
| 12‡ | 33½ | 53·73 | 78·8 | 222 | .. | .. | .. | .. | .. |
| 13 | 28½ | 63·16 | 92·63 | 273 | .. | .. | .. | .. | .. |

* Self-action only. † Brakes not applied at the proper time.
‡ Train consisting of two carriages, and weighing 18 tons 4 cwt. In the other experiments there were three carriages, weighing 27 tons 6 cwt.

Making a reduction of the preceding results, the following values of $f = f_1$, representing the comparative retarding powers of the brakes in each case, are arrived at:—

| Fay. | | Newall. | |
|---|---|---|---|
| 7·9749 | | 6·7765 | |
| 7·0512 | | 6·2813 | |
| 6·9480 | | 5·0810 | |
| 7·4074 | Mean 6·7030. | 5·4292 | Mean 5·4984. |
| 6·5979 | | 4·8929 | |
| 5·3076 | | 4·6625 | |
| 6·3062 | | 5·2385 | |
| 6·0311 | | 5·5555 | |

In this case the brakes of Fay exhibit a superiority in the ratio of 6·7030 to 5·4984, or as 1215 to 1000; or making a correction, as above stated, for the friction of the carriages, the relative efficiency of Fay's and Newall's brakes would stand in the ratio of 6·553 to 5·4084, or as 1210 to 1000.

*Experiments with Flap-Brakes, with the Engine detached.*—These experiments, Table VI., were made in precisely the same manner as the last, the trains consisting of three carriages with brakes to each, loaded to 9 tons 2 cwt.

TABLE VI.—FLAP-BRAKES, ENGINE DETACHED.

| FAY. | | | | | NEWALL. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. | No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. |
| 1 | 35 | 51·43 | 75·43 | 158⅓ | 1 | 36 | 50· | 73·33 | 132⅓ |
| 2 | 35 | 51·43 | 75·43 | 162⅔ | 2 | 36 | 50 | 73·33 | 123 |
| 3* | 32 | 54·54 | 80· | 184 | 3* | 35 | 51·43 | 75·43 | 192 |

* Self-action only.

Reducing the results, the comparative efficiency is:—

| Fay. | | Newall. | |
|---|---|---|---|
| 5·9889 | | 6·7560 | |
| 5·8294 | Mean 5·8718. | 7·2870 | Mean 6·3272 |
| 5·7971 | | 4·9387 | |

In this case the superiority lies with Newall, in the ratio of 6·3272 to 5·8718, or as 1000 to 928.

*Experiments with the Engine attached to the Train.*—These experiments were made with slide-brakes, upon the same ground and in the same manner as the last experiments. The rails also were in the same dry condition. The only difference was that the engine and tender remained attached to the train, instead of being uncoupled, and the tender-brake was applied as rapidly as possible along with the other brakes.

TABLE VII.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, WITH ENGINE NOT DISCONNECTED FROM TRAIN.

Weight of engine, 24 tons; weight of tender, average 10 tons; weight of train, 27½ tons; weight of tank engine, 30 tons.

| FAY. | | | | | NEWALL. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. | No. | Time of Running ¼ Mile, in Seconds. | Speed, in Miles an Hour. | Velocity, in Feet a Second. | Distance of Pulling up, in Yards. |
| 1 | 56⅓ | 31·8 | 46·7 | 121⅓ | 1 | 53 | 33·96 | 49·81 | 124⅘ |
| 2 | 53 | 33·96 | 49·81 | 137 | 2 | 48½ | 37·11 | 54·43 | 169⅓ |
| 3 | 43 | 41·86 | 61·39 | 192½ | 3 | 43 | 41·86 | 61·39 | 221 |
| 4* | 35 | 51·43 | 75·43 | 274 | .. | .. | .. | .. | |

* Tank engine.

Reducing these results, the comparative retarding force is found to be:

| Fay. | | Newall. | |
|---|---|---|---|
| 2·9956<br>3·0184<br>3·2663 | Mean 3·0934. | 3·3169<br>2·9160<br>2·8422 | Mean 3·025 |

where the efficiency of the brakes is almost identical. Fay having an advantage, in the ratio of 1022 to 1000.

From the above extended and somewhat laborious experiments, the following summary of results is derived:—

TABLE VIII.—GENERAL SUMMARY OF RESULTS OF EXPERIMENTS WITH NEWALL'S AND FAY'S BRAKES.

| | Average Number of Experiments. | | Average Efficiency of Brakes. | |
|---|---|---|---|---|
| | Fay. | Newall. | Fay. | Newall. |
| Oldham Incline, Table I. .. | 7 | 7 | 1·8538 | 1·7436 |
| Southport „ „ II. .. | 5 | 1 | 3·6256 | 4·9700 |
| „ „ „ III. .. | 1 | 1 | 3·2329 | 3·1416 |
| „ „ „ V. .. | 8 | 8 | 6·7030 | 5·4984 |
| „ „ „ VI. .. | 3 | 3 | 5·8718 | 6·3272 |
| „ „ „ VII. .. | 3 | 3 | 3·0934 | 3·0250 |

The general average from this Table gives, for the efficiency of Fay's brakes, 4·0634, and for that of Newall's 4·1650, showing a slight superiority in favour of the latter.

The following conclusions seem borne out by these experiments:—

1st. That with slide-brakes the greater number of experiments gave a manifest superiority to Fay's.

2nd. That with flap-brakes there was a decided advantage on the side of Newall.

3rd. That when the train was braked, with the engine attached, the results were uniform; neither Fay's brakes nor Newall's gaining any decided superiority.

During the whole of these trials there was a strong feeling of rivalry, which rendered necessary the greatest caution, in order to prevent any interference, which might modify and vitiate the results. To reconcile these differences, and to obtain correct returns, Unwin was employed to take charge of the train, and to see that the brakes were applied at the right time; also to register the velocity of the train, and the distance of pulling up, during each experiment. There is therefore every reason to believe that the results recorded are a strict expression of the efficiency of the brakes, at their respective times of trial.

*Yolland's Experiments with Newall and Fay's Railway Brakes.*—It may be interesting to compare with these results the earlier experiments obtained by Colonel Yolland, on the same class of brakes, and under somewhat similar conditions of trial, as detailed in his Report to the Board of Trade, dated the 12th June, 1858. These results do not appear to have been reduced, hitherto, to any common standard of comparison. But as they embrace a wider range of circumstances of gradient, weather, weight, &c., than in Fairbairn's experiments, they will instructively test the method of reduction employed.

In the experiments on the Accrington incline the trains weighed 72 tons each, and consisted of six weighted carriages, used in all the experiments, and of three carriages fitted with Newall's, and three with Fay's brakes, respectively, and employed alternately. The required velocity was obtained by permitting the carriages to descend a distance of from three-quarters of a mile to a mile along the incline, which falls at the rate of 1 in 38 to 1 in 40. The initial velocity at the instant of applying the brakes was ascertained by observing the time required to traverse the quarter of a mile immediately preceding; and the mean velocity over this distance is used in

the reductions as the initial velocity of the train, although it is slightly below the real speed, at the instant of braking.

TABLE IX.—EXPERIMENTS ON THE ACCRINGTON INCLINE, WITH NEWALL'S AND FAY'S BRAKES, FEBRUARY 27, 1858. Weather fine.

| No. | | Velocity, in Feet a Second. | Gradient falling – . | Distance of Braking, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 2 | Newall .. | 69·47 | – 1 in 39 | 1587 | Heavier train. |
| 3 | | 52·8 | – 1 in 39 | 777 | |
| 4 | | 48·9 | – 1 in 39 | 822 | |
| 5 | | 28·7 | – 1 in 40 | 414 | Three continuous brakes. |
| 6 | | 69·47 | – 1 in 39 | 1114 | |
| 7 | | 62·86 | – 1 in 40 | 1208 | |
| 9 | | 30·7 | – 1 in 39 | 430 | |
| 10 | Fay .. .. | 60· | – 1 in 39 | 923 | |

Reducing the results in Table IX., the retarding force is:—

| Newall. | Fay. |
|---|---|
| 1·0275 | 1·4754 |
| 1·4233 | |
| 1·3102 | |
| 1·1363 — Mean 1·3231. | |
| 1·5285 | |
| 1·3705 | |
| 1·1700 | |

It will be remarked that in these experiments the brakes were applied to a part of the train only. Hence, for comparison with the Southport experiments, a reduction must be made, to the condition of trains with brakes throughout, by the formula [6] already explained in that way,

$$f_1 = \frac{W}{w} f.$$

The retarding force in terms of the mass of the carriages actually braked is:—

| Newall. | Fay. |
|---|---|
| 3·7955 | 3·9345 |
| 3·4940 | |
| 3·0301 | |
| 4·0759 — Mean 3·5516. | |
| 3·6547 | |
| 3·1200 | |

Showing an advantage to Fay in the ratio of 1107 to 1000. But a comparison is here scarcely fair, seeing the disproportion in the number of experiments with each brake.

TABLE X.—EXPERIMENTS ON THE ACCRINGTON INCLINE, WITH NEWALL'S AND FAY'S BRAKES, FEBRUARY 28, 1858. Weather misty.

| No. | | Velocity, in Feet a Second. | Gradient, falling – . | Distance of Braking, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 11 | Fay .. .. | 66· | – 1 in 39 | 2060 | Three continuous brakes. |
| 13 | | 62·86 | – 1 in 39 | 1660 | |
| 16 | | 50·77 | – 1 in 39 | 1070 | |
| 17 | | 35·67 | – 1 in 40 | 492 | |
| 12 | Newall .. | 60· | – 1 in 39 | 2142 | |
| 14 | | 60· | – 1 in 39 | 1754 | |
| 15 | | 50·77 | – 1 in 39 | 1450 | |
| 18 | | 69·47 | – 1 in 132 | 880 | Tender and ditto. |

The results in Table X. show that the mean of the retarding force is:—

| Fay. | | Newall. | |
|---|---|---|---|
| 1·178 | | 1·105 | |
| 1·221 — Mean 1·220. | | 1·167 — Mean 1·131. | |
| 1·227 | | 1·122 | |
| 1·257 | | | |

Or with brakes throughout:—

| Fay. | | Newall. | |
|---|---|---|---|
| 3·141 | | 2·946 | |
| 3·256 — Mean 3·255. | | 3·112 — Mean 3·017. | |
| 3·272 | | 2·992 | |
| 3·352 | | | |

Giving a slight advantage to Fay, in the ratio of 1070 to 1000.

TABLE XI.—EXPERIMENTS WITH NEWALL'S BRAKES, BETWEEN LIVERPOOL AND PRESTON, FEBRUARY 22, 1858.

Train of carriages weighing 83 tons 18 cwt.; engine, 29 tons 2 cwt.; tender, 13 tons 4 cwt.

| No. | | Velocity, in Feet a Second. | Gradient, rising +, falling −. | Distance of Braking, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 1 | Newall .. | 57·39 | − 1 in 135 | 285 | Tender and six brakes. |
| 2 | | 48·88 | − 1 in 180 | 208 | |
| 3 | | 66·00 | + 1 in 135 | 206 | |
| 4 | | 45·52 | + 1 in 168 | 246 | Tender and self-action of six brakes. |
| 6 | | 57·39 | − 1 in 150 | 276 | Tender and six brakes. |
| 7 | | 48·88 | − 1 in 130 | 204 | |

Reducing as before, these data give .. .. .. $\left\{\begin{array}{l} f = 2{\cdot}165 \\ f = 2{\cdot}095 \\ f = 3{\cdot}285 \\ f = 2{\cdot}204 \\ f = 2{\cdot}201 \end{array}\right\}$ Mean 2·390;

or, reduced in the ratio of the weight on the wheels braked to the weight of the train .. .. .. .. .. $\left\{\begin{array}{l} f_1 = 4{\cdot}304 \\ f_1 = 4{\cdot}164 \\ f_1 = 6{\cdot}530 \\ f_1 = 4{\cdot}381 \\ f_1 = 4{\cdot}375 \end{array}\right\}$ Mean 4·671.

This agrees with the value $f_1 = 3{\cdot}5516$, obtained in the first experiments at Accrington, with the rails dry, and is in excess of the value $f_1 = 3{\cdot}017$, obtained with the rails wetted by the mist.

For experiment No. 4, with the self-action of the brakes alone, $f = 1{\cdot}211$, or about one-half the full brake-power.

TABLE XII.—EXPERIMENTS BETWEEN PRESTON AND LIVERPOOL, WITH NEWALL'S RAILWAY BRAKES, FEBRUARY 22, 1858.

Weight of train, 101 tons 1¾ cwt.; weight on brakes, 71 tons 19½ cwt.

| No. | | Velocity, in Feet a Second. | Gradient, rising +, falling −. | Distance of Pulling up, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 8 | Newall .. | 73·33 | 0 | 196 | Tender and seven continuous brakes. |
| 9 | | 57·39 | + 1 in 402 | 130 | |
| 10 | | 44· | 0 | 107 | |
| 11 | | 60· | − 1 in 120 | 167 | |

Reducing these results .. .. .. .. .. .. $\left\{\begin{array}{l} f = 4{\cdot}567 \\ f = 2{\cdot}975 \\ f = 3{\cdot}015 \\ f = 4{\cdot}118 \end{array}\right\}$ Mean 3·668;

or, when the train is braked throughout .. .. .. $\left\{\begin{array}{l} f_1 = 6{\cdot}406 \\ f_1 = 4{\cdot}173 \\ f_1 = 4{\cdot}229 \\ f_1 = 5{\cdot}776 \end{array}\right\}$ Mean 5·146.

This would seem to indicate that the brakes act more efficiently, the more nearly they are applied throughout the whole train.

TABLE XIII.—EXPERIMENTS BETWEEN LIVERPOOL AND PRESTON, WITH NEWALL'S BRAKES, FEBRUARY 23, 1858.

| No. | | Velocity, in Feet a Second. | Gradient, rising +, falling −. | Distance of Pulling up, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 1 | Newall .. | 77·65 | − 1 in 204 | 314 | All the brakes. |
| 2 | | 73·33 | 0 | 179 | |
| 3 | | 52·8 | 0 | 183 | All but the tender. |
| 4 | | 73·33 | − 1 in 132 | 227 | |
| 5 | | 66· | + 1 in 135 | 189 | All the brakes. |
| 6 | | 73·33 | 0 | 249 | |
| 7 | | 62·86 | − 1 in 150 | 208 | |
| 8 | | 44· | − 1 in 700 | 138 | |
| 9 | | 77·65 | − 1 in 120 | 235 | |

Reducing .. .. .. .. .. .. .. .. .. .. $\left\{\begin{array}{l} f = 3{\cdot}3582 \\ f = 5{\cdot}0068 \\ f = 3{\cdot}7041 \\ f = 4{\cdot}0797 \\ f = 3\ 5892 \\ f = 2{\cdot}9516 \\ f = 2{\cdot}2922 \\ f = 4{\cdot}0081 \end{array}\right\}$ Mean 3·6249.

or, when further reduced in the ratio of the weight of the whole train to the weight on the wheels braked .. $\left\{\begin{array}{l} f_1 = 3{\cdot}9660 \\ f_1 = 5{\cdot}9130 \\ f_1 = 4{\cdot}3745 \\ f_1 = 4{\cdot}8181 \\ f_1 = 4{\cdot}2506 \\ f_1 = 3{\cdot}4858 \\ f_1 = 4{\cdot}7335 \end{array}\right\}$ Mean 4·5057.

The preceding results obtained by Yolland are as follows:—

| | Fay. | Newall. | |
|---|---|---|---|
| Engine detached | 3·9345 | 3·5516 | Dry. |
| | 3·255 | 3·017 | Wet. |
| Engine attached .. .. .. .. .. | 4·671, 5·146, 4·505 | | Mean 4·774. |

TABLE XIV.—EXPERIMENTS WITH M'CONNELL'S STEAM SLEDGE-BRAKE, BETWEEN BLETCHLEY AND OXFORD, JANUARY 19, 1858.

The engine weighed 29 tons; the tender, 14 tons 10 cwt.; the carriages, 102 tons 9 cwt.; the guards' vans, 10 tons 4¾ cwt.: steam-sledges assumed at 7 tons 2 cwt.

| No. | | Velocity, in Feet a Second. | Gradient, rising +, falling −. | Distance of Pulling up, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 1 | M'Connell's steam-brake. | 27·5 | + 1 in 150 | 430 | None. |
| 2 | | 32·19 | + 1 in 142 | 285 | Steam and guard's. |
| 3 | | 19·35 | + 1 in 142 | 163 | Guard's. |
| 4 | | 52·8 | − 1 in 214 | 590 | All. |
| 5 | | 60· | − 1 in 149 | 870 | Steam and tender. |
| 6 | | 48·88 | − 1 in 209 | 673 | All. |
| 7 | | 36·67 | − 1 in 1430 | 623 | Steam. |
| 8 | | 55· | − 1 in 163 | 880 | All. |
| 9 | | 55· | 0 | 763 | Tender and guard's. |
| 10 | | 57·39 | 0 | 1320 | Steam. |
| 11 | | 52·8 | − 1 in 2211 | 496 | All. |
| 12 | | 60· | 0 | 540 | All. |
| 13 | | 55· | + 1 in 2211 | 345 | All. |
| 14 | | 47·14 | 0 | 538 | Tender and guard's. |
| 15 | | 47·14 | − 1 in 452 | 388 | All. |
| 16 | | 62·86 | + 1 in 163 | 669 | All. |
| 17 | | 57·39 | 0 | 880 | Tender and guard's. |
| 18 | | 55· | + 1 in 209 | 1194 | Steam. |

Reducing these results:—

| No. | | No. | |
|---|---|---|---|
| 2 .. .. | $f = 0{\cdot}03793$ | 11 .. .. | $f = 0{\cdot}93677$ |
| 3 .. .. | $f = 0{\cdot}01562$ | 12 .. .. | $f = 1\ 11111$ |
| 4 .. .. | $f = 0{\cdot}93791$ | 13 .. .. | $f = 1{\cdot}42800$ |
| 5 .. .. | $f = 0{\cdot}90567$ | 14 .. .. | $f = 0{\cdot}64824$ |
| 6 .. .. | $f = 0{\cdot}74567$ | 15 .. .. | $f = 1{\cdot}02560$ |
| 7 .. .. | $f = 0{\cdot}38224$ | 16 .. .. | $f = 0{\cdot}78880$ |
| 8 .. .. | $f = 0{\cdot}77041$ | 17 .. .. | $f = 0{\cdot}62379$ |
| 9 .. .. | $f = 0{\cdot}66076$ | 18 .. .. | $f = 0{\cdot}42225$ |
| 10 .. .. | $f = 0{\cdot}41586$ | | |

Separating those experiments which were made on different brakes, and taking the mean of those made on the same, the value of each brake respectively is as follows:—

| | |
|---|---|
| For the guard's brake .. .. .. .. .. .. .. | $f = 0{\cdot}1562$ |
| „ tender-brake .. .. .. .. .. .. .. | $f = 0{\cdot}4989$ |
| „ steam-brake .. .. .. .. .. .. .. | $f = 0{\cdot}4373$ |
| „ steam and tender brakes .. .. .. .. | $f = 0{\cdot}9057$ |
| „ steam and guard's brakes .. .. .. .. | $f = 0{\cdot}3793$ |
| „ guard's and tender brakes .. .. .. .. | $f = 0{\cdot}6443$ |
| „ guard's, steam, and tender brakes .. .. | $f = 0{\cdot}9678$ |

These numbers represent the actual proportion of the brake-power supplied in the experiments by each brake or set of brakes. The efficiency of the brakes in relation to the weight upon them is:—

| | | |
|---|---|---|
| For the guard's brake | .. .. .. .. .. .. | $f_1 = 2{\cdot}2268$ |
| „ tender-brake | .. .. .. .. .. .. .. | $f_1 = 5{\cdot}0216$ |
| „ steam-brake | .. .. .. .. .. .. .. | $f_1 = 9{\cdot}1176$ |
| „ steam and tender brakes | .. .. .. .. | $f_1 = 6{\cdot}1197$ |
| „ steam and guard's brakes | .. .. .. .. | $f_1 = 3{\cdot}1930$ |
| „ guard's and tender brakes | .. .. .. .. | $f_1 = 3{\cdot}8014$ |
| „ guard's, steam, and tender brakes | .. .. | $f_1 = 4{\cdot}4365$ |

This shows that, in proportion to the weight upon it, a sledge-brake, which can be applied instantly, acts most efficiently.

*Colonel Yolland's Experiments with M. Guérin's Self-acting Brake.*—The train in the first four experiments consisted of an engine, tender, and nineteen carriages, two being fitted with M. Guérin's brakes. The total weight of the train was 151·88 tons. In the remaining experiments two ordinary brake-vans were substituted for M. Guérin's, the total weight being then 152·8 tons.

TABLE XV.—EXPERIMENTS BETWEEN ERITH AND WOOLWICH, AUGUST 27, 1858.

| No. | | Velocity, in Feet a Second. | Gradient, rising +, falling −. | Distance of Pulling up, in Yards. | Remarks. |
|---|---|---|---|---|---|
| 1 | M. Guérin's brakes. | 50·78 | − 1 in 912 | 597 | Tender and two Guérin brakes. |
| 2 | | 62·86 | 0 | 738 | |
| 3 | | 57·39 | 0 | 552 | |
| 4 | | 45·52 | + 1 in 912 | 395 | |
| 5 | Ordinary brake-vans. | 48·57 | − 1 in 912 | 359 | Tender and two ordinary brakes. |
| 6 | | 66· | 0 | 593 | |
| 7 | | 50·77 | 0 | 521 | |
| 8 | | 52·8 | + 1 in 912 | 510 | |

Reducing these results:—

| M. Guérin's Brakes. | | Ordinary Brakes. | |
|---|---|---|---|
| 0·075488 | Mean 0·0870. | 0·11300 | Mean 0·1013. |
| 0·089238 | | 0·12243 | |
| 0·099445 | | 0·08245 | |
| 0·083898 | | 0·08757 | |

From these experiments, M. Guérin's brakes appear to be less efficient than two equally heavy brake-vans of the ordinary description, when used in conjunction with a tender-brake, in the ratio of 1165 to 1000.

The value of $f_1$ for the mean of these experiments gives:—

| | |
|---|---|
| For M. Guérin's brake | .. .. .. .. .. .. .. .. 0·5169 |
| „ the guard's ordinary brake | .. .. .. .. .. .. 0·5874 |

We do not pretend to know the reason why, but Guérin's brake gave better results when tried in France.

*Experiments with Ingram's Auxiliary Brake, on the Manchester, Sheffield, and Lincolnshire Railway.*—When these experiments were made, the weather was bad, rain falling the whole time. The train weighed 124 tons ¼ cwt.; the tender, 17 tons; the carriages to which Ingram's brake was applied, 25 tons 17⅕ cwt.

TABLE XVI.—EXPERIMENTS WITH INGRAM'S BRAKES, OCTOBER 18, 1858.

| No. | | Velocity, in Feet a Second. | Gradient. | Distance of Pulling up, in Yards. | Time in Stopping, in Seconds. |
|---|---|---|---|---|---|
| 3 | Ingram's brake. | 46·9 | 1 in 124 | 870 | 90 |
| 3 | | 44·0 | 1 in 124 | 795 | 77 |
| 4 | | 51·3 | 1 in 133 | 768 | 65 |
| 7 | Tender .. | 54·2 | 1 in 120 | 1320 | 134 |
| 9 | | 46·9 | 1 in 120 | 1152 | 114 |

Reducing these results, on the assumption that the gradients were all falling ones:—

| | Ingram's Brakes. | | Tender-Brakes. | |
|---|---|---|---|---|
| $f$ = | 0·68096 | Mean 0·7217. | 0·63921 | Mean 0·6128. |
| | 0·66545 | | 0·58646 | |
| | 0·81870 | | | |

Hence, $f_2$ = with Ingram's brake .. .. .. .. .. .. .. .. 3·4619

the tender-brake .. .. .. .. .. .. .. .. 4·4712

Ingram's brake thus showing a somewhat less efficiency than the tender-brake.

It should be here observed that the work employed to move a body over a horizontal distance, added to the work due to the gravity in elevating the body a vertical height, is the same as that employed in moving the body on a curve joining the extreme points, since a curve may be supposed to be made up of a number of straight lines; hence the uniform work upon the whole curve will be equal to the uniform work done upon the horizontal projection, added to the work done in opposition to gravity in raising the body, no matter what form be given to the path described.

*Reduction of the Retarding Force to Units of the Weight of the Brake Carriages.*—In the preceding reductions it was found most convenient to know the retarding force in terms of the mass of the train. For practical purposes, however, it is convenient to state the retarding force in terms of the weight upon the brake carriages, and, to be guided by precedent in this matter, it seems best to state the retarding force in pounds to the ton weight on the braked wheels, that is, in the same terms as the normal friction of the train is usually stated. Calling, therefore, $f_2$ the mean resistance in pounds a ton, in the moving mass of all the forces tending to destroy motion, of which the principal is the friction of the brake, then $f_2 = f_1 \times \frac{2240}{32 \cdot 19} = 69 \cdot 587 f_1$.

ORDINARY BRAKES.

| | Retardation, in lbs. a ton, on Wheels Braked. | |
|---|---|---|
| Guard's van .. .. .. .. .. | 154·9 .. .. | Yolland. |
| Tender-brake .. .. .. .. | 349·4 .. .. | „ |
| Tender and guard's brakes .. .. | 264·5 .. .. | „ |
| Tender-brake .. .. .. .. | 311·0 .. .. | M. S. and L. Railway. |

All the above results, with the exception of the last, were obtained in dry weather.

| | | |
|---|---|---|
| Tender-brake .. .. .. .. | 302·4 .. .. | Fairbairn. |

NEWALL.

| Tables. | | Mean Retarding Force, in lbs. a ton weight, of Braked Carriages | |
|---|---|---|---|
| I. | Slide-brakes (wet and foggy) .. .. | 121·3 .. .. | Fairbairn. |
| III. | „ „ (slightly wet) .. .. .. | 237·7 .. .. | „ |
| II. | „ „ (dry and frosty) .. .. | 345·8 .. .. | „ |
| V. | „ „ (dry and warm) .. .. | 382·6 .. .. | „ |
| IV. | Flap-brakes (dry and warm) .. .. | 440·3 .. .. | „ |
| IX. | „ „ (dry) .. .. .. .. .. | 247·1 .. .. | Yolland. |
| X. | „ „ (misty) .. .. .. .. | 209·7 .. .. | „ |
| XI. | „ „ (dry) .. .. .. .. .. | 325·4 .. .. | „ |
| XII. | „ „ (dry) .. .. .. .. .. | 358·9 .. .. | „ |
| XIII. | „ „ (dry) .. .. .. .. .. | 313·5 .. .. | „ |

The mean of the experiments from Tables II., IV., and V., gives the retarding force at 389·6 lbs. per ton. The mean of Yolland's, from Tables IX., XI., XII., XIII., is 311·2 lbs.; or, omitting Table IX., 332·6 lbs. Bearing in mind that Fairbairn's results were obtained under circumstances of competition, and that there was in consequence the greatest care in the adjustment of the brakes, the above results agree sufficiently well. Hence also may be observed the very large diminution of the retardation of the brakes in wet and foggy weather. In wet weather the retardation does not appear to exceed 200 lbs. a ton; and in foggy weather, with the rails greasy, it appears that it may be reduced to 121 lbs., or nearly one-fourth of the maximum in dry warm weather.

FAY.

| Tables. | | Mean Retarding Force, in lbs. a ton weight, of Braked Carriages | |
|---|---|---|---|
| I. | Flap-brakes (wet and foggy) .. .. | 129·0 .. .. | Fairbairn. |
| III. | „ „ (slightly wet) .. .. .. | 224·9 .. .. | „ |
| II. | „ „ (dry) .. .. .. .. .. | 252·2 .. .. | „ |
| IV. | „ „ (dry) .. .. .. .. .. | 408·6 .. .. | „ |
| V. | Slide-brakes (dry) .. .. .. .. | 466·4 .. .. | „ |
| IX. | „ „ (dry) .. .. .. .. .. | 273·7 .. .. | Yolland. |
| X. | „ „ (misty) .. .. .. .. | 226·5 .. .. | „ |

There the maximum retardation amounts to 466·4 lbs. a ton, or nearly one-fifth of the weight of the braked carriages. The mean of Tables II., IV., V., in dry weather, gives 375·7 lbs. a ton.

M'CONNELL'S STEAM-BRAKE.

| Table XIV. | Mean Retardation, in lbs. a ton weight, on Wheels and Sledges Braked. | |
|---|---|---|
| Guard's van .. .. .. .. .. .. .. .. | 154·9 .. .. | Yolland. |
| Tender-brake .. .. .. .. .. .. .. .. | 349·4 .. .. | „ |
| Steam-brake .. .. .. .. .. .. .. .. | 634·4 .. .. | „ |
| Steam and tender brakes .. .. .. .. .. | 425·8 .. .. | „ |
| Steam and guard's brakes .. .. .. .. .. | 222·1 .. .. | „ |
| Guard's and tender brakes .. .. .. .. .. | 264·5 .. .. | „ |
| Guard's, steam, and tender brakes .. .. .. | 308·7 .. .. | „ |

These reductions seem to show that, in proportion to the weight upon it, the sledge-brake is more efficient than any brake applied to the wheels. Of course it is not asserted that the sledge-brake could be employed in lieu of the present arrangement; but that it renders useful, in retarding the train, a larger proportion of the weight on it.

### M. Guerin's Brake.

Table XV.

| | Mean Retarding Force, in lbs. a ton, on Brake Carriages. | |
|---|---|---|
| M. Guérin's and tender brakes .. .. | 35·9 .. .. | Yolland. |
| Ordinary van and tender brakes .. | 40·8 .. .. | ,, |

Both these brakes were, for some reason, acting inefficiently.

### Ingram's Brake.

Table XVI.

| | Mean Retarding Force, in lbs. a ton weight, of the Carriages Braked. | |
|---|---|---|
| Ingram's and tender brakes .. .. .. | 240·9 .. .. | M. S. and L. Railway. |

### General Summary.

| | | Ratio of Weight on Brakes, to Retarding Force generated by them, or Mean Coefficient of Friction for each Brake. |
|---|---|---|
| Newall's (dry) | Fairbairn | from 0·1544 to 0·1965 |
| ,, (wet) | Fairbairn | 0·0542 |
| Fay's (dry) | Fairbairn | from 0·1126 to 0·2082 |
| ,, (wet) | Fairbairn | 0·0576 |
| Newall's (dry) | Yolland | 0·1116 |
| Fay's (dry) | Yolland | 0·1020 |
| Ingram's (wet) | | 0·1075 |
| Guérin's (dry) | | 0·01048 |
| M'Connell's steam-brake | | 0·28325 |

That is, the retarding force generated by these brakes varies from $\frac{1}{100}$ to $\frac{5}{18}$ of the weight of the carriages to which brakes are applied, and is ordinarily from $\frac{1}{10}$ to $\frac{1}{5}$.

This agrees very well with the deductions from experiments on the friction of metal on metal, which give for smooth surfaces a coefficient varying from 0·15 to 0·2, or nearly identical with the best experiments above reported.

*Formulas.*—To find the distance on a level line required to bring a train to a stand by braking:—

Let $s$ = the distance of pulling up, in yards;
$v$ = the velocity of the train, in feet per second;
$w$ = the weight on the braked wheels, in tons;
$W$ = the total weight of the train, in tons;
$\theta$ = the inclination of the incline to the horizon, if the train is on a gradient, so that if the incline rises 1 ft. in $x$ ft., then $\sin. \theta = \frac{1}{x}$;
$g$ = the action of gravity = 32·19.

Then, if the train is braked throughout, and on a level line, $s = \frac{v^2}{6 f_1}$; and if brakes are applied to a part of the train only, $s = \frac{v^2}{6 f_1} \times \frac{W}{w}$; or, if the train is on an incline,

$$s = \frac{v^2}{6 f_1 \pm 6 g \sin. \theta} \times \frac{W}{w},$$

where the + or − sign is to be taken, according as the incline falls or rises.

The value of the coefficient $f_1$ must be selected from the Tables of Experiments already given, that coefficient being selected which was obtained under circumstances most nearly approaching those of the case to be determined.

Thus, if the trains are stopped by the friction of their bearings, and so on, without the application of brakes, $f_1 = 0{\cdot}13$ (mean), and $6 f_1 = 0{\cdot}78$.

If the brakes are ordinary guard and tender brakes, applied together, $f_1 = 4$, and $6 f_1 = 24$, approximately.

For brakes, such as Newall's and Fay's, acting with maximum efficiency, $f_1 = 5{\cdot}5$ to $6{\cdot}5$, and $6 f_1 = 33{\cdot}0$ to $39{\cdot}0$.

Thus, supposing it is required to ascertain the distance in which a train weighing 60 tons, with brakes to 20 tons weight of the carriages, would be brought to rest, in ascending an incline of 1 in 27, at a velocity of 60 ft. a second; then taking $f_1 = 4$,

$$s = \frac{v^2}{6 f_1 + 6 g \sin. \theta} \times \frac{W}{w} = \frac{(60 \times 60)}{6 \times 4 + 6 \times 32{\cdot}19 \times \frac{1}{27}} \times \frac{60}{20} = 116 \text{ yds.}$$

If the rails are wetted by rain, the value of the coefficients given above must be taken at one-third less, and if greasy, their value may be reduced by as much as one-half or three-fourths.

It is convenient, in some cases, to estimate the braking power in time rather than in distance.

Now, theoretically, putting $t$ = the time of braking, in seconds, then $t = \frac{v}{f}$. In practice this does not hold strictly true; hence $t = \frac{v}{f} - x$, where $x$ is a constant to be derived from the experiments; $\therefore x = t + \frac{v}{f}$.

Now, from the Oldham experiments:—

For Fay's brakes .. .. .. .. $x = 3, 6, 8, 8, 3, 8.$
For Newall's brakes .. .. .. .. $x = 4, 2, 5, 0, 7, 8, 9.$
Hence mean .. .. .. .. $x = 5\cdot4.$

$$\therefore \quad t = \frac{v}{f} - 5\cdot4 = \left(\frac{v}{f_1} \times \frac{W}{w}\right) - 5\cdot4.$$

The above formulas will be found sufficient for the purpose of ascertaining the amount of brake-power required to arrest the motion of any train, within such a distance as may be considered safe by the railway company, or by the engineer; or in any given case, to determine the distance within which a train of any required weight may be stopped when travelling at any velocity.

*Steam-Brakes.*—During the last few years engineers have undertaken to construct railway brakes which would act more effectively than those previously used. Every engineer knows the imperfections of the apparatus and of plans for effecting the retardation or stopping of trains. He knows further how urgent the demand for such means is; the more so as it is desirable to take away from the tender as much weight as possible, and strengthen and lighten the engine by an extended application of steel, so that the tender may carry more fuel and feed-water, without increasing the total weight of the engine and loaded tender, or diminishing the power of the engine. Independently of these considerations, it is generally acknowledged that the retarding power ought to proceed from the same parts of the mechanism which transfers the propelling power, and that a properly constructed brake ought to be operated by the accumulated force when not required to propel the train. With those considerations in view, numerous experiments were made, and plans tried; however, applicable and satisfactory results were not obtained.

A correct investigation will show the error of providing for the carriages or wagons a separate brake-mechanism, even should the power to operate such mechanism be taken from the locomotive boiler. With locomotives, however, means must be found which will not only allow us to accumulate a sufficient retarding force in the boiler, but which will also give us the power to regulate its application and intensity, so as to destroy, gradually, the work conserved in the train and due to the weight of the train and its uniform velocity. At the same time the means provided must have the power to diminish by degrees, and ultimately to reverse, the tractive power of the engine.

We propose to examine the four following systems of steam-brakes, namely:—

1. The reversing of the valve-gear (System Lechatelier-Ricour).
2. The compression of the steam (System Zeh).
3. The compression of the air in the cylinder (System de Bergues).
4. The repression of the steam (Frein a Vapeur de Landsee, and Steam-repression Brake of Krauss and Co.).

The steam-brake of Krauss and Co. was designed by Professor Linde, of Munich.

The systems 1 and 4 depend upon the same principle, that is, the counter-effect of the steam; but the methods of application are different.

*The Reversing of the Valve-gear.*—The motion of any locomotive can be diminished by simply reversing the valve-gear; but it is easy to understand that the counter-effect of the steam increases quickly the pressure of the steam in the boiler. This is, however, a minor reason why the counter-effect of the steam should be applied, to suddenly stop trains, only in exceptional cases, for another disadvantage of a more serious character is to be met with. The exhaust-port opens in locomotives, not directly into the open air, but communicates, through the exhaust-pipe, with the interior of the smoke-box. Whilst the cylinders are now drawing in the air, they will thus not be filled with pure air, but with the gases of combustion from the smoke-box, which have not only a very high temperature of 400°, 500°, and upwards, but which also carry with them a great many unconsumed parts of the fuel. The disadvantageous influence which the practice of using the counter-pressure of the steam will have upon the engine and boiler of a locomotive will thus be at once understood. But let us examine the distribution of the steam produced by the reversing of the valve-motion, and we shall find that it is very disadvantageous, and becomes still more disadvantageous the faster the engines work and the more powerful the effect becomes.

Suppose the crank to stand at one of the dead points A, Fig. 1248, that it travels in the direction indicated by the arrow, and thus contrary to the valve-motion; then the angle of advance becomes negative. The steam enters the cylinder behind the piston, until the latter has reached the point B, where, at the ordinary working of the engine, the steam in front of the piston began to be admitted. It is a very short distance, but the clearances of the pistons are filled, and a small but accelerated expansion of the steam takes place till the piston reaches the point C. The compression began formerly at that point, but now a communication with the exhaust is effected, which remains open and allows the air to enter the cylinder behind the piston during the full forward stroke. This communication with the exhaust-pipe continues in front of the piston to the point D, where formerly the release of the steam began; an insignificant compression of the air follows next, till the piston arrives at E, where formerly the expansion of the steam began. But only now, after the piston has travelled a part of its stroke and its velocity becomes great in proportion to the velocity of the crank, the admission of the counter-effect begins through the slowly-opening

port; the piston has to travel a farther distance, dependent upon its velocity, before it meets in front with steam of sufficient pressure. The most important period has almost passed inefficaciously, and the work done by the piston is thus very insignificant. That work is represented in a graphical manner in Fig. 1248, by the dark hatchings *a b c d*, after the accelerated expansion work *c d e* has been deducted.

1251 1249. 1250. 1248.

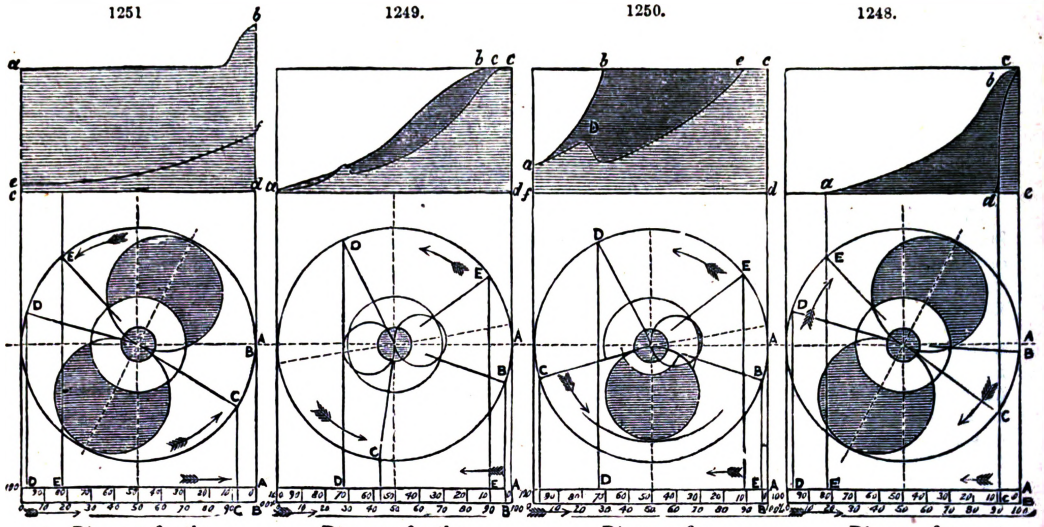


Diagram for the *steam-repression* brake. Diagram for the compression of the steam. *System Zeh.* Diagram for Landsee's steam-brake. Diagram for reversing the valve-gear.

Fig. 1248.—*e c*, Pressure of the steam in the boiler. E, Beginning of the admission of the counter-steam in front of the piston. D, Exhaust shut before the piston. B, The admission of steam cut off behind the piston. C, Exhaust opens behind the piston.

Fig. 1249.—D, Exhaust opens behind the piston. E, Expansion begins behind the piston. B, Admission of the steam begins in front of the piston. C, Exhaust shut before the piston.

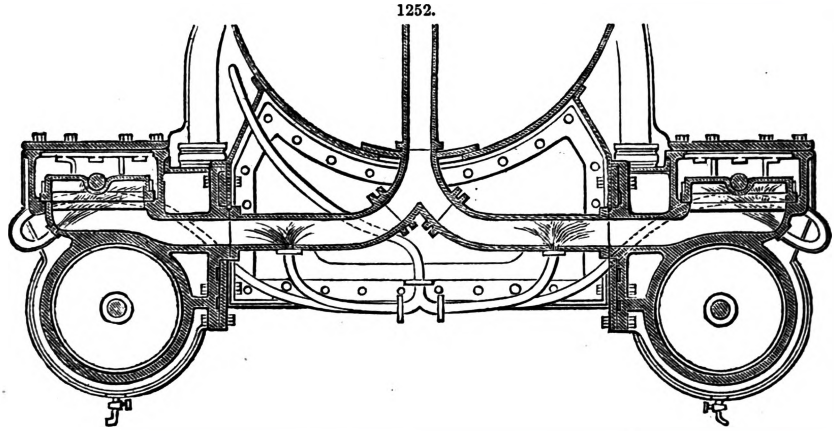
Fig. 1250.—D, Exhaust opens behind the piston. E, Expansion begins behind the piston. B, Communication with the steam-chest begins in front of the piston. C, The admission of the counter-steam begins in front of the piston.

Fig. 1251.—B, Communication with the steam-chest begins in front of the piston. C, Compression begins in front of the piston. D, Admission of the counter-steam begins behind the piston. E, Communication with the steam-chest shut behind the piston.

Engineers have always had sufficient reason to regret that drivers should be prohibited to apply this simple and powerful means of stopping trains; and, moreover, retardation by means of friction-brakes, considered theoretically as well as practically, is imperfect, since the *vis viva* of the trains had to be entirely destroyed by an external application of the brake, to diminish the velocity.

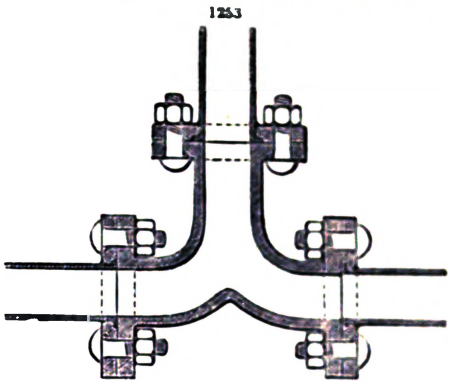
It is not surprising, under such circumstances, that the proposition of Lechatelier was soon approved of and applied first in France and then in Switzerland. According to M. Lechatelier's plan, Figs. 1252, 1253, a pipe is led from the exhaust-pipe of the engine to a small closed vessel,

1252.



which is connected with the boiler by two other pipes, each furnished with a cock. One of these communicates with the boiler above, and the other below the water line, and by means of them

a mixture of steam and water can be introduced into the closed vessel, and from it, led by the pipe first mentioned, to the exhaust-pipe. The action of this arrangement is as follows:—When the engine is reversed for the purpose of retarding the train, the pistons would, under ordinary circumstances, pump air into the boiler, mixed with dust from the smoke-box, cutting and damaging the working surfaces of the cylinders and valves.




To prevent this damage, M. Lechatelier's plan provides for the admission of the mixture of steam and water into the blast-pipe when the engine is reversed, and the pistons then pump this mixture, instead of air, into the boiler. The water serves to lubricate the pistons, and the quantity admitted is just about as much as will be evaporated by the heat generated by the friction of the working parts. The supply of steam to the blast-pipe is generally allowed to be somewhat in excess of the quantity which can be pumped back into the boiler by the pistons, and the small quantity, which is thus constantly escaping at the blast-nozzle, serves to prevent the admission of a current of air. But experience has not only shown that Lechatelier's method, especially at a high speed of the engine, is in many cases not powerful enough, but that the admission of the proper quantity of steam and water requires great skill from the drivers.

*The Compression of the Steam.*—The method proposed by Zeh takes place by shutting the exhaust-pipe and placing the valve-gear on a high grade of expansion, so that the steam has to perform not only little work, but the escape of the expanded steam is also prevented, and the latter is thus compressed at the backward stroke of the piston.

The diagram, Fig. 1249, shows that the intensity of the effect can only be increased to a trifling degree. The pressure of the steam in front of the piston and at the commencement of the stroke can only be little more than that of the atmosphere, and the piston has to travel half of its stroke before the compression at C begins. When the crank arrives at B, almost at the end of the stroke, the pressure of the steam in front of the piston is still much less than the pressure of the steam in the boiler which acts now upon the piston for the remainder of the stroke. We get thus at first a retarding work, represented in the figure by the area *a b c c d*; next a propelling work, represented by the area *a e c d*, and composed of the area *c e*, the work done by the full pressure of the steam, and the area *e a*, the work done by the expansion of the steam. The comparison between the two works shows in fact a very insignificant effect of this method.

*The Compression of Air in the Cylinders* has been proposed by M. de Bergues as a means for retarding the motion of locomotives. According to M. de Bergues' plan, the regulator and the blast-pipe are shut, the admission-pipe is put in communication with an air-vessel which is provided with a safety-valve, the exhaust-pipe is put in communication with the atmosphere, and the valve-motion is reversed. The counter-pressure can thus be increased to a certain degree, independently of the pressure in the boiler; but here also the disadvantages appear to be very great. In the first instance, M. de Bergues sacrifices the relation to the boiler; and hence he cannot accumulate a sufficient retarding force. Next, he reverses the valve-motion, and has thus from the beginning a disadvantageous distribution of steam, which, moreover, must produce a limited effect of the power, as the pressure of the steam is very variable.

The air-vessel must not be too large, in order to produce, quickly, highly compressed air; a perceptible reduction of the pressure of the compressed air effects the filling of the steam-cylinders. The compression produces, besides, a high temperature in the cylinders, which requires special precautions and a very abundant oiling; finally, the arrangement and management of the apparatus are rather complicated. It gives very good results for short runs, but not under prolonged working.

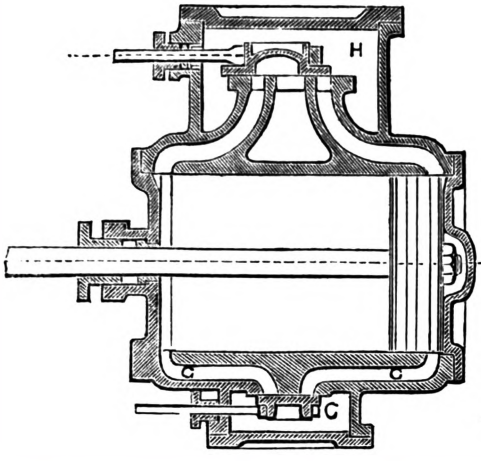
*Steam-Brake of M. de Landsee.*—M. de Landsee acts upon the very correct principle to produce the retarding power by means of using steam from the boiler as a back-pressure upon the pistons in a more advantageous manner than with the reversing of the valve-gear. For that purpose, M. de Landsee adds to the engine for the admission of the steam in front of the piston a second valve-gear, to the cylinder another steam-chest and another system of ports; for the movement of the second valve he fixes an eccentric rectangular to the crank, a link and the necessary gear. In order to retard the motion of the engine, the exhaust-pipe is shut, the main valve-gear is placed on a high grade of expansion, so that the steam behind the piston performs a little work by expansion, whilst the steam in front of the piston, which has entered the cylinder through the second steam-chest G, Figs. 1254, 1255, is pressed back into the boiler, and acts thus by its *repression* upon the piston in comparison to the compression performed in the cylinder.

It must be admitted that this arrangement offers a satisfactory solution of the existing problem; but if the apparatus is destined to produce a more powerful effect than the apparatus previously examined, two moments of some importance have been neglected.

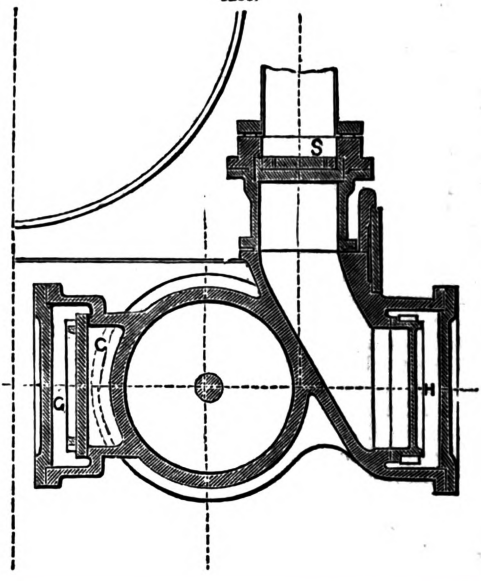
Let us examine what occurs during one revolution of the crank. The main valve H is supposed to have opened the port as much as the linear advance. The clearance of the piston, which in the present construction is enlarged on account of the second port communicating with the steam-chest G, amounting at least to $7\frac{1}{2}$ per cent. of the volume of the cylinder, is still filled with steam from the last repression. If we suppose $\frac{1}{10}$ to be the degree of expansion, or $17\frac{1}{2}$ per cent. the filling of the cylinders, *c c* will show in a graphical manner, in Fig. 1250, the

work done under the full pressure of the steam, and *e* D the work performed during the expansion of the steam, where D represents the beginning of the release of the steam, which takes place

1254.




1255.




after the piston has travelled about 70 per cent. of the stroke; the steam will thus have lost in a proportion of 77·5 to 17·5 of its pressure. Although the exhaust is shut and prevents the escape of this steam of almost ¼ of the pressure of the steam in the boiler, a considerable volume of fresh steam enters the cylinder from that part of the exhaust which extends to the distribution-valve S, and which had been filled during the preceding repression. If we suppose the volume of that part to be 20 per cent. of that of the cylinder, the pressure of the steam will increase in a proportion of

$$\frac{17\cdot5}{77\cdot5} : \frac{17\cdot5}{77\cdot5} + \left(1 - \frac{17\cdot5}{77\cdot5}\right)\frac{20}{97\cdot5}, \text{ or } \frac{17\cdot5}{77\cdot5} : \frac{17\cdot5}{77\cdot5} + 0\cdot16.$$

At the end of the stroke the pressure will have again decreased in a proportion of 127·5 : 97·5, and we get thus with a pressure of 8 atmospheres in the boiler, after all, only a pressure of

$$p = 8\left(\frac{17\cdot5}{97\cdot5} + 0\cdot16\right)\frac{97\cdot5}{127\cdot5} = 2\cdot3 \text{ atmospheres.}$$

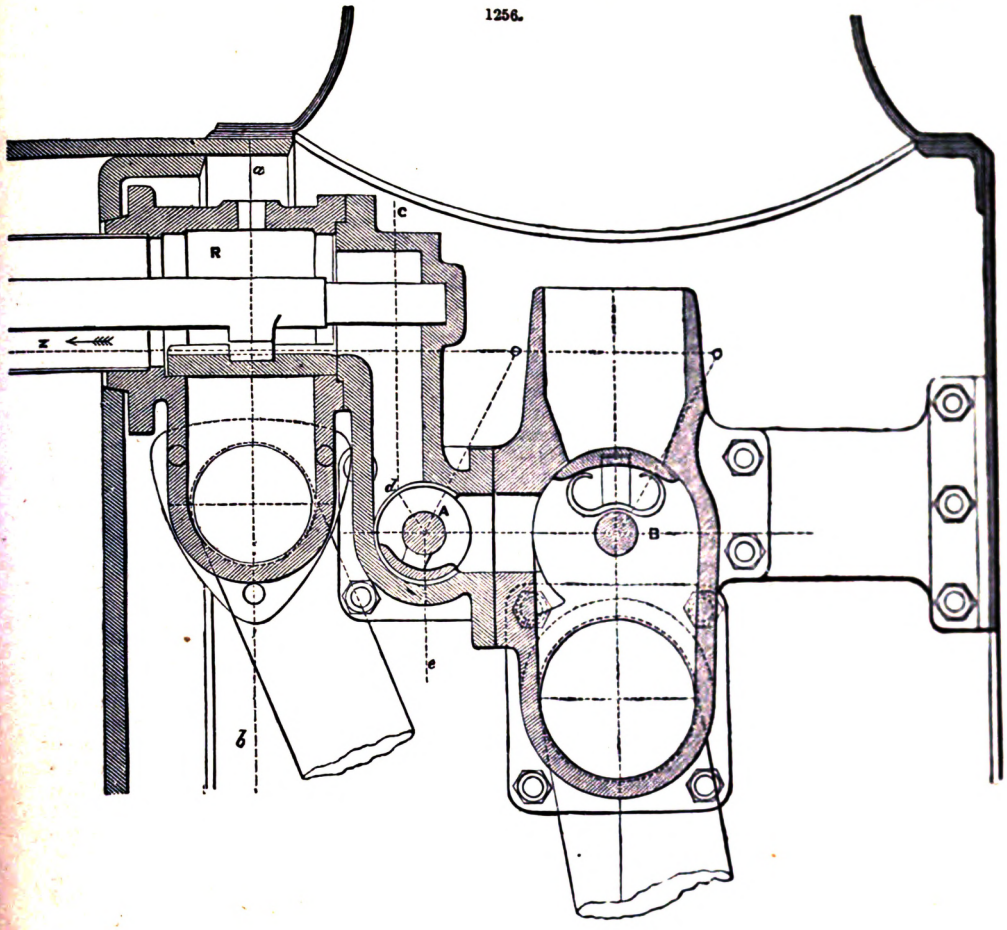
The value of the accelerated work is thus higher than at first calculated; it amounts at least to 45 per cent. of the total work performed by the piston (according to Boyle's law). But another circumstance, which reduces the retarding power at a high speed of the locomotive, has been entirely neglected, namely, the want of lead for the admission of the counter-steam. Of course, this lead could only be obtained on account of a still more disadvantageous distribution of the steam on the backward stroke of the piston, or by fixing a fourth eccentric. The valve G must thus travel a distance corresponding to its lap, before it admits the counter-steam into the cylinder, after the piston has reached the end of the stroke. At a high speed, the piston will have to travel a considerable part of its stroke before it meets in front with steam, the pressure of which is equal to that in the boiler.

The whole construction, although very ingenious, is too complicated, and the large clearances of the pistons, required by the two systems of ports are great disadvantages. The simple principle, to admit steam into the cylinder, and to have it pressed back into the boiler by the movement of the piston, without any modification of the valve-motion, but by allowing the steam to enter the cylinders through the exhaust-pipes, instead of through the ordinary steam-pipes, has been adopted in

*The Repression Brake of Krauss and Co., Munich.*—This plan consists in an arrangement by means of which the steam can be made to enter the cylinders through the exhaust-pipes, instead of through the ordinary steam-pipes, the blast-nozzle being at the same time closed, and the steam admitted through the exhaust-pipes being pumped back, partly into the boiler, and partly into the steam-chests, from which it escapes through an adjustable valve into the chimney. Of course, the engine has not to be reversed, as in M. Lechatelier's arrangement.

The simplest arrangement is to place the regulator in the smoke-box, and to provide it with a segment-valve, as shown in Figs. 1256 to 1259. The regulator-valve R is connected with the blast-pipe by a tube A, and the blast-pipe is also provided with a segment-valve B. When the inlet to the steam-chest is shut by the first-mentioned valve, and the communication with the blast-pipe is open, the outlet of the latter being shut, then the steam passes from the boiler, through the tube and the blast-pipe, into the outlets or discharged ports of the slide-valve, and rushes against the piston with a counter-pressure equal to the steam-pressure during nearly the full stroke, that is to say, during the time that the steam is acting to work the engine; during this counter-pressure the steam is returned into the boiler. When about $\frac{9}{10}$ of the stroke has been

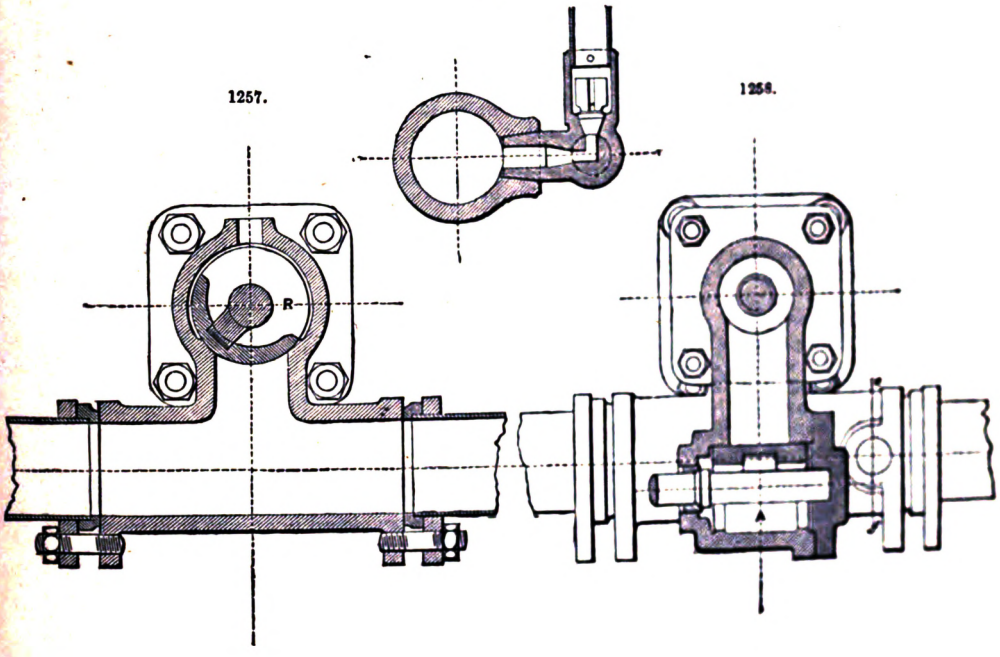
1256.




1259.

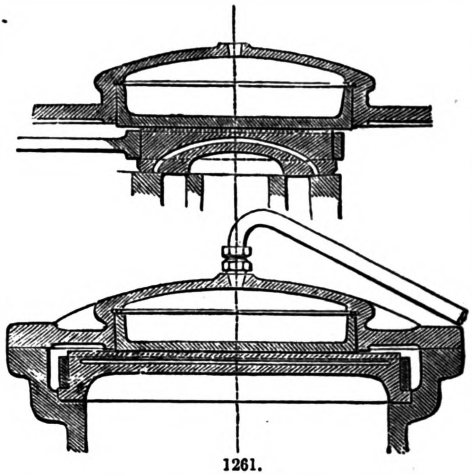
1257.

1258.



accomplished, the outlet is shut, and the steam being still in the cylinder, is further compressed till the ordinary inlet is opened by the slide-valve; and this steam can then escape to the steam-chest, and from there through a valve to the chimney. This valve is regulated by a cock, and can be put in communication through the inlet-tube, Fig. 1261, with the steam-chest, but during the working of the engine the valve is shut. This valve regulates the quantity of steam which is retained in the steam-chest, and also regulates the work of the brake. The regulation of the back-pressure may also be effected by regulating the steam-pressure in the blast-pipe, and this is done by enlarging or narrowing the inlet opening, also by admitting steam to the steam-chest through the regulator-valve and expansion-valve; that is to say, by the introduction of steam into the cylinder on both sides of the piston. To simplify the working of the apparatus, the regulator-valve, the blast-pipe valve, and the valve with the regulating cock, are connected by levers, so that by simply moving the regulator the engine can be driven at full speed, or can be reversed. By this arrangement of the apparatus it is possible nearly instantaneously to change the propelling force of the engine into a retarding force. When the piston is nearly at the end of the stroke, on the other side, the slide-valve begins to open the admission openings, and the steam passes into the empty cylinder, so that the latter is full of steam when the piston returns; this steam is now forced back into the boiler. This action continues till the slide-valve shuts the communication between the cylinder and the admission opening; the confined steam is then further compressed. This compression is at the highest point when the slide-valve is in communication with the cylinder and the steam-chest just before the crank is at the dead point; the steam then passes into the steam-chest and through the valve. It is necessary that the slide-valves should be prevented from being pressed back by the compressed steam, and Figs. 1257 to 1261 show the arrangement employed for that purpose. The valve, it will be seen, is fitted with a piston, at the back of which is a hole, which is connected by a tube with the blast-pipe, so that while braking, the steam can act upon the piston and prevent the pressing back of the slide-valve. Fig. 1251 shows the distribution and action of the steam in a graphical manner. At D, where formerly the release of the steam began, the admission of the counter-steam into the cylinder commences, so that when the piston arrives at the end of its stroke, the whole cylinder is filled with counter-steam, which has to be pressed back into the boiler by the piston, till the crank has reached the point C, when the communication with the blast-pipe is cut off. The remaining steam is compressed until the point B is reached, when it escapes through the valve into the steam-chest. Whilst the steam acts with full pressure during the whole stroke *in front* of the piston, the communication with the steam-chest is maintained *behind* the piston, until the crank arrives at the point E.

1260.

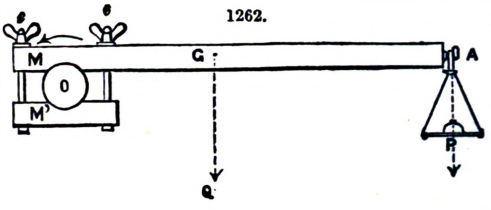


1261.

*Dynamometer-Brake.—Prony's Friction Dynamometer-Brake.*—A friction brake may be employed to measure the power applied to, and the mechanical effect produced by, a shaft or other part of a machine which revolves uniformly; it must be clearly understood that neither the power nor the effect can be measured unless the revolutions continue uniform after the brake is applied and adjusted. Piobert and Fardy, in 1821, applied a brake as a dynamometer to determine the power of water-wheels; but M. Prony first applied a brake to determine the power transmitted by steam.

It was determined by experiment that friction had a uniform resisting power that might be intensified by pressure: Prony contrived a brake to apply this retarding power to bring revolving shafts to given or required uniform velocities, so that the power applied by, or conserved in, a machine might be measured. Prony's brake, in its simplest form, is shown in Fig. 1262. Let the circle O be a cross-section of a horizontal shaft, which is revolving, but not uniformly; M, M, A, is the brake, the pressure of which may be increased or diminished by tightening or loosening the screws *e*, *e*, respectively. A circular cavity is made in the two wooden jaws M, M', which receives the revolving shaft O; the upper jaw M is lengthened to support a balance scale A P, which may be loaded with any required weight. The operation which we are about to describe must not be confounded with that of weighing a body by means of a lever and fixed prop. Now, suppose that a shaft O makes *k* uniform revolutions a minute, and, at the same time, drives any machinery whatever, and that we require to know the amount of power employed in driving such machinery. To effect this object, the communication between the shaft O and the machinery driven by it must be removed, and the brake so tightened on the shaft that it will make just *k* revolutions a minute. While the brake is being pressed by the screws *e*, *e*, to obtain the necessary amount of friction, it is prevented from being turned with the shaft by props. Then weights are placed in the scale A, to bring the arm M A into a horizontal position: the props which prevented the brake from being

1262.



whirled round with the snaft are not in contact with the brake when M A is horizontal. When the brake is thus screwed up and poised, the shaft must continue to make a uniform revolutions a minute; then the power transmitted by the shaft O may be calculated. Let P be the weight suspended at A, and $p$ the perpendicular distance from the centre of O to the line A P. Q the weight of the scale and that part of the apparatus which assists the weight P; G its centre of gravity, and $q$ the perpendicular distance from O to the line G Q. The reaction of the friction of the jaws M, M′, upon the revolving shaft O may be resolved into normal forces $n$, $n'$, $n$, . . . . and tangental forces $f$, $f'$, $f''$, . . . . acting in the direction of the rotatory motion. When the equilibrium of the apparatus is established, the sum of the moments of these different forces, in relation to the centre of O, must be equal to zero. But the normal forces have no moments, and if $r$ be put for the radius of the shaft, we have the equation $fr + f'r + f''r + \ldots - Pp - Qq = 0$. Or putting $\Sigma fr$ for the sum of the forces $fr + f'r + f''r + \ldots$ we have the equation

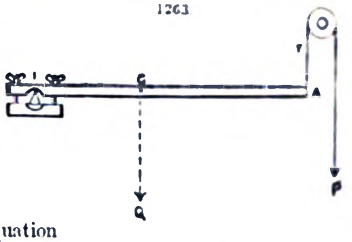
$$\Sigma fr = Pp + Qq. \qquad [1]$$

Taking the angular velocity at the distance of a unit from the centre of O (see ANGULAR VELOCITY), the work of friction for one revolution is found by multiplying $\Sigma fr$ by $2\pi$, $\pi$ being put = 3·14159 . . . .; whence, if N = the number of revolutions a minute, and if $\mathcal{P}_f$ be put for the work of the friction in a second, we have $\mathcal{P}_f = \frac{2\pi N}{60} \Sigma fr$. When the value of the general expression conventionally written $\Sigma fr$, from equation [1], is substituted, we have

$$\mathcal{P}_f = \frac{\pi N}{30} (Pp + Qq). \qquad [2]$$

The weight P, required to bring A M to a horizontal position, and the perpendicular distance $p$, are known. The moment $Qq$ may be found in the following manner:—The apparatus is weighed, as shown in Fig. 1263, by supporting the brake, detached, on a knife-edge I, and bringing the lever I A into a horizontal position by means of a weight P′ attached to a cord, which passes over a fixed pulley, and is connected to the end A of the lever. The friction of the pulley being neglected, the tension T is equal to the force P′, and we have the equation

1263




$$Tp = Qq \text{ or } P'p = Qq. \qquad [3]$$

The weight P′ is termed the permanent load.

Substituting $P'p$ for $Qq$ in equation [2], we obtain the equation

$$\mathcal{P}_f = \frac{\pi N}{30} (P + P')p. \qquad [4]$$

N the uniform revolutions and P become known when the brake is perfectly adjusted.

If, for example, $p = 2^{m}{\cdot}50$; $P' = 30^{k}$, and the shaft O, Fig. 1262, to make continually forty uniform revolutions a minute when $P = 120^{k}$, then N = 40, and the general expression

$$\mathcal{P}_f = \frac{3{\cdot}14159265 \times 40}{30} (120 + 30) \times (2{\cdot}5) = 1570{\cdot}79633$$

French units of work, or 1570·79633 kilogrammes raised the height of 1 mètre. The French consider a horse-power = 75 kilogrammes raised 1 mètre in a second. 75 French units of work are equal to 542·5 English units of work; $\frac{33000}{60} = 550$; but 550 : 542·5 :: 1 : ·9864; therefore an English horse-power is a French horse-power, as 1 is to ·9864 nearly. 1570·79633 ÷ 75 = 20·94 horse-power, according to the French method of measurement.

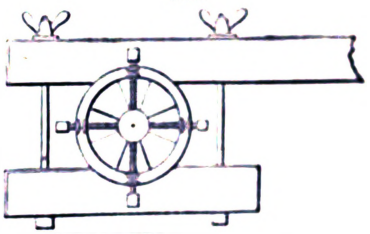
Again, suppose $p = 8$ ft.; P′ = 50 lbs.; P = 250 lbs.; and N = 40; then

$$\mathcal{P}_f = \frac{3{\cdot}1416 \times 40}{30} (250 + 50)\, 8 = 10052{\cdot}12 \text{ units of work a minute;}$$

$$\therefore \frac{10052{\cdot}12}{550} = 18{\cdot}28 \text{ horse-power (English).}$$

In practice, the jaws are not directly applied to the shaft; but if the latter is of cast iron, a circular frame, expressly framed and bored for that purpose, is fastened to it by means of adjusting-screws. If the shaft is of timber, and of a large size, it is surrounded by a ring formed of two parts and provided with screws for its correct centering; this ring is fastened to the shaft by means of wedges. In both cases the jaws of the brake are applied to the circular frame or ring, as shown in Fig. 1264.

1264.



If the product $\Sigma fr$ or $r\Sigma f$ remains the same for an equal number of horse-power, $\Sigma f$ is so much greater, the smaller $r$ is taken. But the friction may thus become too great, and by altering, consequently, the contacting surfaces, it will also lose its uniformity. Experience has proved that with

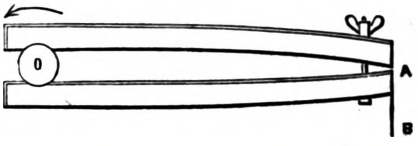
| a diameter of between | and a velocity of between | the power can be measured of |
|---|---|---|
| 16 and 20 centimètres, | 20 and 30 revolutions per minute, | 6 or 8 horses, |
| 30 „ 40 „ | 15 „ 30 „ „ | 15 „ 25 „ |
| 60 „ 80 „ | 15 „ 30 „ „ | 40 „ 70 „ |

A high speed is, besides, favourable to the regularity of the experiment, as M. Morin has confirmed at Bonchet. A uniform friction is necessary for the maintenance of the equilibrium of the lever during the rotatory motion of the shaft; the lever assumes always a little oscillating motion, which is of no consequence as long as it keeps within strict limits; but if these oscillations become considerable, an irregularity in the friction has taken place, and the retarding power of the friction cannot under such circumstances be measured.

On account of the length of the lever, the weight at A, Fig. 1262, may of itself tighten the screws; in order to remove this inconvenience, which sometimes produces false results, M. Poncelet has proposed to make the two jaws of equal length, and to place the bolts near the point A, Fig. 1265. The flexibility of the wood permits a gradual tightening, which renders this arrangement preferable to the ordinary one.

To establish stable equilibrium, M. Poncelet applied the weight, not to the point A itself, but to the end of a vertical rod A B, fastened to one of the jaws. It thus happens, that if the lever begins to turn round with the shaft, the lever-arm of the weight P increases immediately, and the friction ceasing to be preponderant, the apparatus returns to its equilibrium.

1265.




A little more than half the brake is shown in this figure.

If the shaft is vertical, the weight cannot be applied directly to the end of the lever, but a cord fastened to it is made to pass horizontally in a perpendicular direction over a fixed pulley.

A plummet suspended before the end of the lever will show the position of the brake when equilibrium is established.

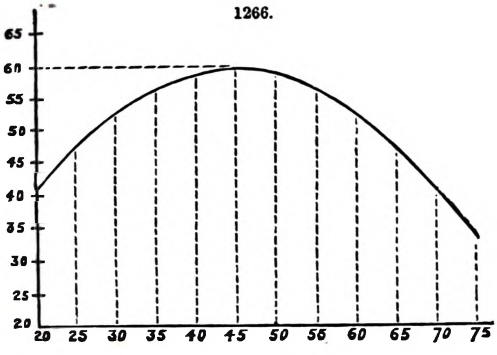
M. Morin has extended the useful application of the brake as a dynamometer, for he does more than measure by it the work done for a given or required uniform velocity of a shaft.

The extended application to which we allude may be thus described:—

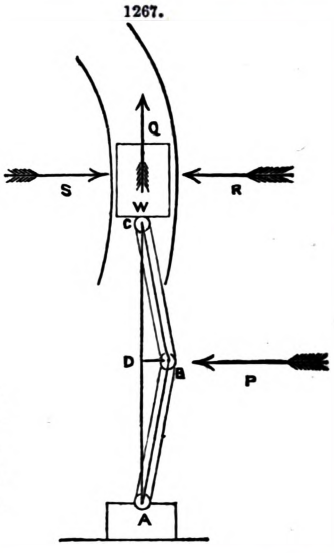
When the shaft turns round without meeting with any resistance, and after the supports of the lever have been removed, a weight between 5 and 10 kilogrammes is placed at the end of the lever; the screws are now tightened, till an equilibrium of the apparatus is established. The uniform velocity or speed of the shaft is measured, and the units of work done are ascertained. A new weight is again added to that already acting at the end of the lever; the screws are made more tight, until equilibrium is again established, and the uniform speed of the shaft and the work performed are determined. The weight at the end of the lever is gradually increased, and the screws for the establishment of an equilibrium tightened, till the shaft stops or turns in an irregular manner. The work done, in each second, is thus obtained for a variety of uniform speeds, from the greatest to the least possible. A curve is drawn, the abscissæ of which represent the velocities, and the co-ordinates the corresponding values of the ratios between the work given by the brake and the work of the motor. This curve indicates the nature and power of the machine; it gives the performed work corresponding to an average uniform speed of a shaft, and, besides, it shows the uniform speed which corresponds to the maximum effect.

Fig. 1266 represents the results of a series of experiments made with a turbine of the System Fontaine. The abscissæ are proportional to the number of revolutions of the wheel a minute, and the co-ordinates represent the corresponding values of the actual effects multiplied by 100. It will be seen from the diagram that the maximum actual effect is produced with about forty-five uniform revolutions, and that this maximum is about 0·60, that is to say, the maximum actual effect is 0·60 of the motive power.

1266.




1267.



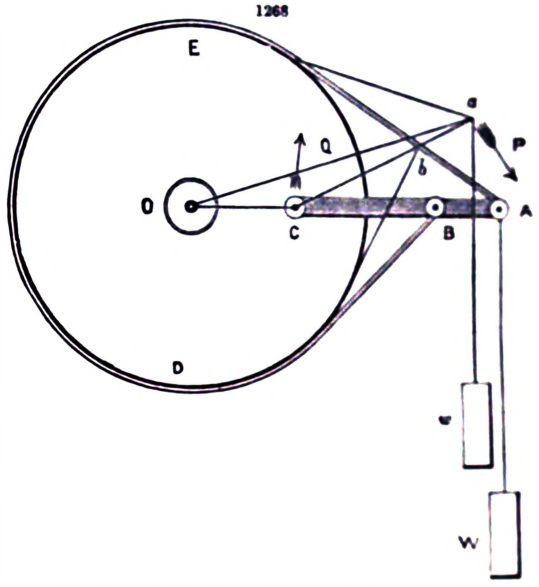

Writers on mechanics, and especially those who attempt to explain the action of a brake employed as a regulator to produce a uniform effect, do not draw a proper distinction between the action of a toggle, and that of a system of compound levers. To place this matter in a clear light we have only to explain the action of a simple toggle-joint, since the properties of the lever are well known.

Let A B = B C = 144·01 in. be the arms of a toggle-joint, Fig 1267; the point A is fixed, but the rod A B may be turned round A as a centre. The joints B and C are also loose, but C is constrained to move in a given path. In the right-angled triangle D C B = D A B and D B perpendicular to A C; putting D B = 2·4 in., then C D = D A = 143·99 in

Suppose a force P of 200 lbs. to be applied at B, in the direction of B D as indicated by the arrow P; when the two bars A B, B C, are brought into a straight line in the direction of the arrow Q, what weight W may be thus moved by the action of the force P? W is constrained to move in a given path by the action of the equal forces R and S. Units of work done by $P = \frac{2 \cdot 4}{12} \times 200 = 40$ units of work. $287 \cdot 98 = A C$, and $A B + B C = 288 \cdot 02$. $288 \cdot 02 - 287 \cdot 98 = \cdot 04$ in., the space over which W must pass in the direction indicated by the arrow Q when B is moved from B to D. $\therefore \frac{\cdot 04}{12} W =$ the units of work done in raising W, consequently $\frac{\cdot 04}{12} W = 40$, or $\frac{W}{300} = 40$; $\therefore$ W = 12000 lbs., which exceeds 5 tons.

John George Appold's brake, which constituted the most important part of the machinery employed to pay-out the French Atlantic Cable, owes its efficiency and success to a judicious application of the toggle-principle to control and regulate the retarding power of friction. The principle upon which Appold formed this mechanical combination may be thus explained:— In Fig. 1268, O is the pivot of the brake-wheel, C the pivot on which the lever C, A, B, works; W represents the weight on the brake. The brake-wheel D E is attached to the paying-out drum. When the friction of the brake-strap B D E A is greater than the weight W, the latter is lifted up and takes a position *w*; C B A takes the position C *b a*; the strap takes the position *b* D E *a*; and the force W may be resolved into two forces, one acting along *a b e*, which is neutralized by the pivot C, and another P acting perpendicular to C *a*; the reacting force Q on the pivot C straightens the toggle O C *a* into its original position O C B A, by a very trifling force Q. Thus the strap *a* E D *b* is relaxed and allows the wheel D E to slip.

1268



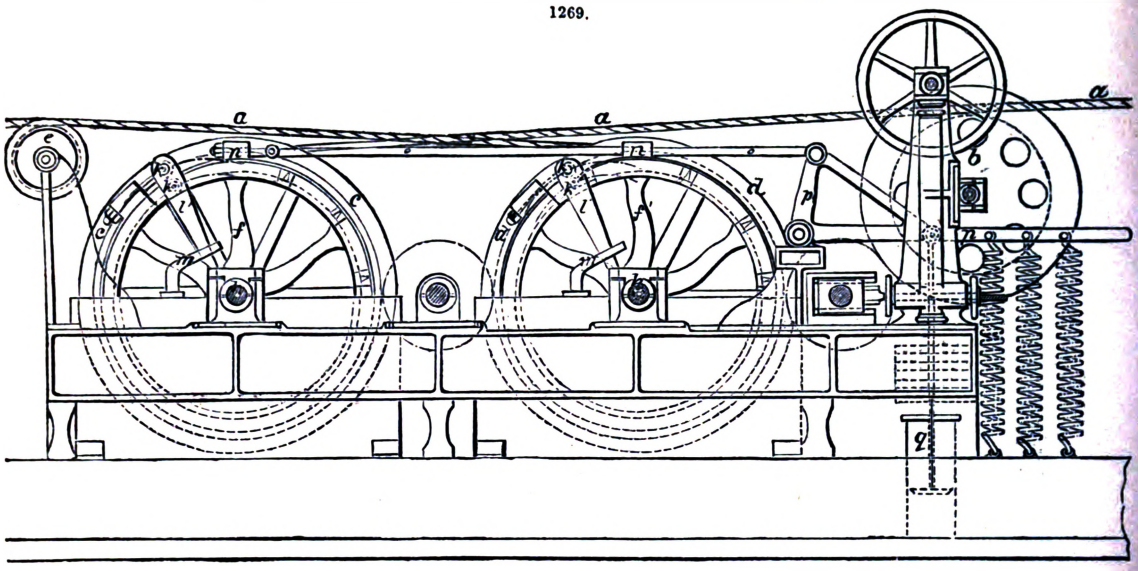

*J. G. Appold's Brake Apparatus for Laying Submarine Telegraphic Cables*, Figs. 1269, 1270, relates to a novel arrangement or construction of a self-acting or self-relieving brake, which may be adapted to the drums, pulleys, or shafts of the apparatus employed for submerging or paying-out telegraphic cables into the water. It is advisable that the strain on the cable while being payed-out into the water should be always maintained as uniform as possible under all circumstances, so that no danger of breaking or damaging the cable by any sudden or undue strain may be apprehended. This object is effected by adapting to the shafts of the paying-out pulleys a drum, on the surface of which a uniform friction is maintained by means of binding bands or straps, which are connected with a weighted vibrating or movable lever. This lever is capable of being weighted to any desired extent, according to the amount of friction required to be maintained. The weights or pressure put on the brake determines the friction thereof on the rotating drums, and consequently the amount of strain on the cable, which strain can be regulated with nicety and great facility. The weights or pressure acting on the vibrating lever or other convenient part of the brake has a tendency to draw the friction strap or band tight on the rotating drum, while the rotation of the drum has a constant tendency to lift the weight, and, by loosening the strap or band on the drum, to relieve the brake from the pressure to which it is subjected. From this it will be understood that these two forces are acting in opposition, and consequently the one has a tendency to counteract the other, so that a uniform strain or friction is always maintained on the rotating drum, the amount of the friction being regulated by the amount of the pressure or weight adapted to the drum.

It will now be understood that the brake is perfectly self-acting, and the friction thereof is always maintained uniform. Provision may be made for relieving the brake from pressure instantaneously when required by means of suitable gearing, whereby the weighted lever or levers is or are lifted up, and the friction straps or bands thereby loosened on the rotating drums. This may be effected by means of a hand-wheel, or by connecting the gearing with a drum or shaft to be actuated by the engine which works the paying-out gear.

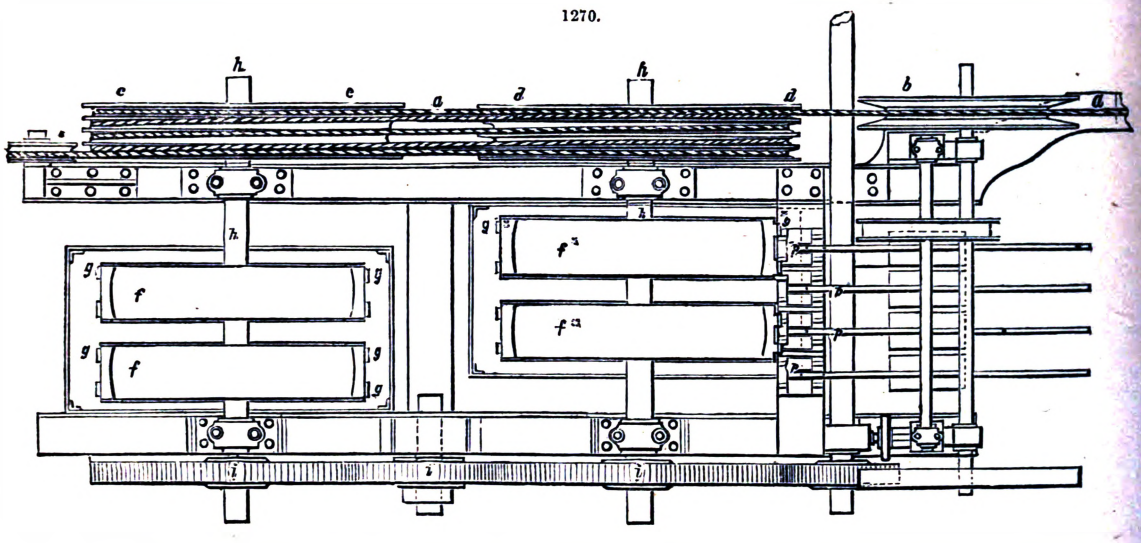
Fig. 1269 is a side elevation, and Fig. 1270 a plan view, of an apparatus for paying-out cables. The cable *a* enters the apparatus over a grooved guide-wheel or pulley *b*, from whence it passes to one of the grooves of a four-grooved drum or pulley *c*, and after passing round this drum or pulley it is conducted round a similar grooved drum or pulley *d*, and so on, the cable being made to pass four times round the two-grooved drums *c* and *d*, from which it is ultimately delivered over another pulley *e*, either directly into the water or through a dynamometer apparatus, whereby the tension or strain on the cable may be ascertained and indicated. On the axles or shafts *h* of each of the grooved drums *c* and *d* are two friction wheels or drums *f*, *f*, *f**, *f**, which

are surrounded by friction-bands $g$, $g$, $g^*$, $g^*$, provided with segmental blocks of wood, which when the bands are drawn tight are made to press on the surface of the wheels or drums $f$, $f^*$, and thereby produce the necessary amount of friction to act as a brake upon the drums. On the ends of the shafts $h$ are mounted the toothed wheels $i$, $i$, Fig. 1270, which are geared together by the pinion $i$, and therefore rotate at the same speed. This toothed gearing, however, is not required while the cable is being lowered or submerged, and therefore it may be thrown out of gear during this operation, and will only be required when the apparatus is used to haul in the cable, as would be required in case of accident to the cable.

1269.



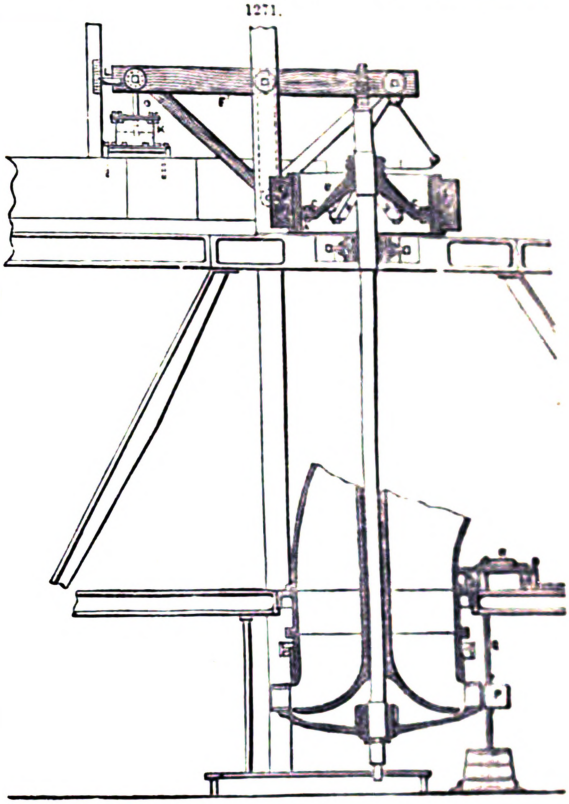

1270.




The ends of the straps or bands $g$, $g^*$, are secured in any convenient manner to pins $k$, $k$, Fig. 1269, fixed on the vibrating levers $l'$, $l'$, each of which passes through a hole made in the arms $m$. The holes in these arms form the centres of motion of the levers $l'$, $l'$, and as these centres of motion are on one side of the centre of the friction wheels $f$, $f^*$, and bands $g$, $g^*$, it follows that by causing these levers $l'$, $l'$, to move on their centres of motion, as indicated in Fig. 1269, they will either tighten or loosen the friction-bands, according to the direction in which the levers are moved. On the upper side of the bands are fixed the blocks $n$, $n$, to which are attached the horizontal rods $o$, $o$, which are secured at one end to one of the blocks $n$ by an adjustable attachment, as shown in Figs. 1269, 1270, and they are jointed at their opposite ends to the vibrating bell-crank levers $p$, $p$. These levers are supported in bearings fixed on the framing, and to the longer end of each is adapted a weight or weights, or a system of springs or other contrivances, whereby the levers may be depressed; and by the levers thus drawing forward the horizontal rods $o$, $o$, they will tend to tighten the friction-bands $g$, $g^*$, round the friction-drums $f$, $f^*$. It will now be understood that as the cable is being payed-out, it (by passing round the grooved pulleys $c$ and $d$) draws the friction-wheels $f$, $f$, round, and by the friction of the wheels $f$ on the bands $g^*$, $g^*$, tends to open

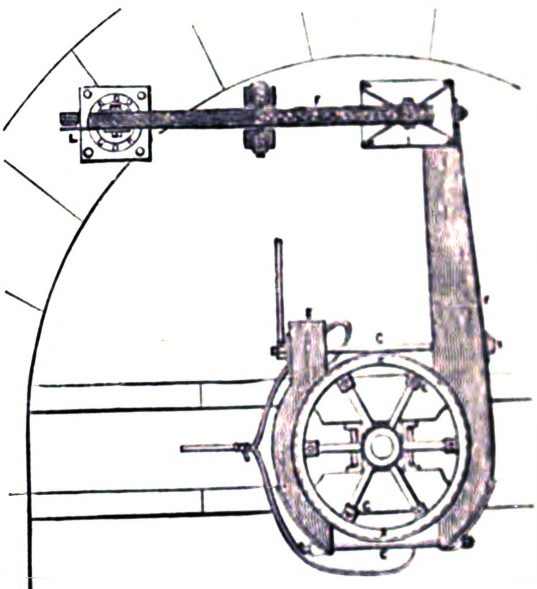
the latter, and thereby relieve the wheels from the friction of the bands. At the same time the weights or springs on the ends of the bell-crank levers $p$, $p$, will draw the friction straps or bands $g$, $g^*$, in the opposite direction, thereby having a tendency to tighten them on the friction-wheels $f$, $f^*$. These two forces will always be acting in contrary directions, and any increase in the action of the one will be counteracted by the other. In order to prevent any jar in the machinery by the weights at the end of the bell-crank levers $p$, $p$, suddenly descending when the friction on the bands or straps $g$, $g^*$, alters, it is convenient to attach to the weights, which are made of a cylindrical or other convenient form, a piston, which is made to work in a cylinder $q$. This cylinder or *dash-pot* is supplied with water, and as the piston is made pretty nearly to fit the internal diameter of the cylinder $q$, the water will to some extent moderate and regulate the motion of the weights, and will prevent them from jumping up and down. It is convenient to cause the friction-wheels to rotate or work in water, as shown at Fig. 1270, for the purpose of keeping them cool.

1271.



When a dynamometer apparatus is employed in conjunction with the paying-out apparatus, for the purpose of indicating the changes that take place from time to time in the tension of the cable, Appold employs an apparatus constructed upon an improved plan, whereby weights are dispensed with, and springs employed in place thereof. The cable when delivered from the paying-out apparatus above described, passes from the delivery pulley under or over a movable pulley, which is mounted on a block that works up and down in vertical guides. This block is supported at a given altitude in the guides by means of coiled or other springs placed either above or below the pulley, which is made to bear against the cable, and as the tension thereof varies, so the pulley with its block is caused to rise or fall in its guides, as is well understood in reference to ordinary dynamometers. This invention shows that John George Appold was a man of considerable genius and profound mechanical skill.

1272.



The Prony dynamometer-*brake* employed by J. B. Francis in making experiments on hydraulic motors is shown in Figs. 1271, 1272; Fig. 1271 is a sectional elevation, and Fig. 1272 is a sectional plan. The friction-pulley A is of cast iron, 5·5 ft. in diameter, 2 ft. wide on the face, and 3 in. thick. It is attached to the vertical shaft by the *spider* B, the *hub* of which occupies the place on the shaft intended for the bevel-gear. The friction-pulley has on its interior circumference six *lugs* C, C, corresponding to the six arms of the spider. The bolt-holes in the ends of the arms are slightly elongated in the direction of the radius, for the purpose of allowing the friction-pulley to expand a little as it becomes heated, without throwing much strain upon the spider. When the *spider* and friction-pulley are at the same temperature, the ends of the arms are in contact with the friction-pulley. The friction-pulley was made of great thickness for two reasons. When the pulley is heated, the arms cease to be in contact with the interior circumference of the pulley, consequently they would not prevent the pressure of the brake from altering the form of the pulley. This renders great stiffness necessary in the pulley itself. Again, it was found that a heavy friction-pulley

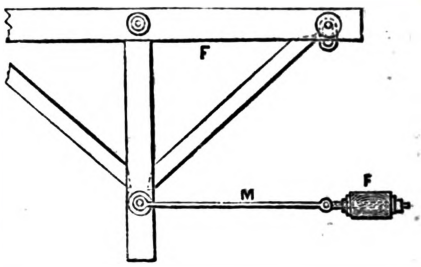
increases more regularity in the motion, operating, in fact, as a fly-wheel, in equalizing small irregularities.

The *brakes* E and F are of maple wood; the two parts are drawn together by the wrought-iron bolts G G, which are 2 in. square.

The *bell-crank* F' carries at one end the scale I, and at the other the piston of the *hydraulic* REGULATOR K; this end carries also the pointer L, which indicates the level of the horizontal arm. The vertical arm is connected with the brake F by the link M, Fig. 1273.

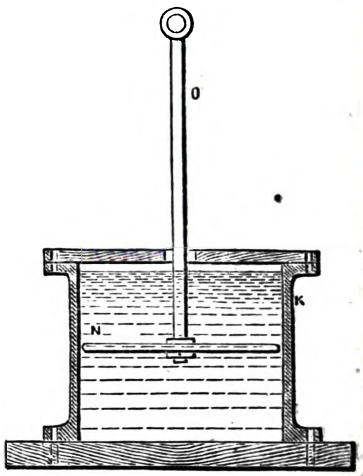
The *hydraulic regulator* K, Figs. 1271, 1272, and 1274, is a very important addition to the Prony dynamometer-brake, first suggested by Boyden in 1844. Its office is to control and modify the violent shocks and irregularities which usually occur in the action of this valuable instrument, and are the cause of some uncertainty in its indications.

1273.




The hydraulic regulator used in these experiments consisted of the cast-iron cylinder K, about 1·5 ft. in diameter, with a bottom of plank, which was strongly bolted to the capping-stone of the wheel-pit, as represented in Fig. 1271. In this cylinder moves the piston N, formed of plate iron 0·5 in. thick, which is connected with the horizontal arm of the bell-crank by the piston-rod O. The circumference of the piston is rounded off, and its diameter is about $\frac{1}{16}$ in. less than the diameter of the interior of the cylinder. The action of the hydraulic regulator is as follows:—The cylinder should be nearly filled with water, or other heavy inelastic fluid. In case of any irregularity in the force of the wheel, or in the friction of the brake, the tendency will be either to raise or lower the weight; in either case the weight cannot move, except with a corresponding movement of the piston. In consequence of the inelasticity of the fluid, the piston can move only by the displacement of a portion of the fluid, which must evidently pass between the edge of the piston and the cylinder; and the area of this space being very small, compared to the area of the piston, the motion of the latter must be slow; giving time to alter the tension of the brake-screws before the piston has moved far. It is plain that this arrangement must arrest all violent shocks; but, however violent and irregular they may be, it is evident that, if the mean force of them is greater in one direction than in the other, the piston must move in the direction of the preponderating force, the resistance to a slow movement being very slight. A small portion of the useful effect of the terbine must be expended in this instrument; probably less, however, than in the rude shocks the brake would be subject to without its use.

1274.




For the purpose of ascertaining the velocity of the wheel, a counter was attached to the top of the vertical shaft, so arranged that a bell was struck at the end of every fifty revolutions of the wheel.

To lubricate the friction-pulley, and at the same time to keep it cool, water was let on to its surface in four jets, two of which are shown in Fig. 1272. These jets were supplied from a large cistern, in the attic of the neighbouring building, kept full by force-pumps. The quantity of water discharged by the four jets was, by a mean of two trials, 0·0288 cubic ft. a second.

In many of the experiments with heavy weights, and consequently slow velocities, oil was used to lubricate the brake, the water, during the experiment, being shut off. It was found that, with a small quantity of oil, the friction between the brake and the pulley was much greater than when the usual quantity of water is applied; consequently, the requisite tension of the brake-screws was much less with the oil, as a lubricator, than with water. This may not be the whole cause of the phenomenon; but, whatever it may be, the ease of regulating in slow velocities is incomparably greater with oil, as a lubricator, than with water applied in a quantity sufficient to keep the pulley cool. The oil was allowed to flow on in two fine continuous streams; it did not, however, prevent the pulley from becoming heated sufficiently to decompose the oil, after running some time, which was distinctly indicated by the smoke and peculiar odour. When these indications became very apparent, the experiment was stopped, and water let on by the jets, until the pulley was cooled. As the pulley became heated, the brake-screws required to be gradually slackened.

In the experiments, in Table II. (see TURBINE WATER-WHEEL), the lubricating fluid was as follows:—

In the first twenty-six experiments, water alone was used.

In the four experiments numbered from 27 to 30, three gallons of linseed-oil were used.

In all the experiments requiring a lubricator, and numbered from 31 to 48, inclusive, linseed-oil was used.

In experiments 49 and 50, resin-oil was used.

In experiments numbered from 51 to 60, inclusive, water alone was used.

In experiment 61, resin-oil was used.

In experiment 62, resin-oil and a small stream of water were used;—in the latter part of the experiment, a good deal of steam was generated by the heat of the friction-pulley.

In experiment 63, resin-oil alone was used.

In experiments numbered from 66 to 72, inclusive, water alone was used.

In experiments numbered from 73 to 79, inclusive, resin-oil and a small stream of water were used.

In experiments numbered from 81 to 84, inclusive, water alone was used.

In experiments 85 and 86, resin-oil and a small stream of water were used.

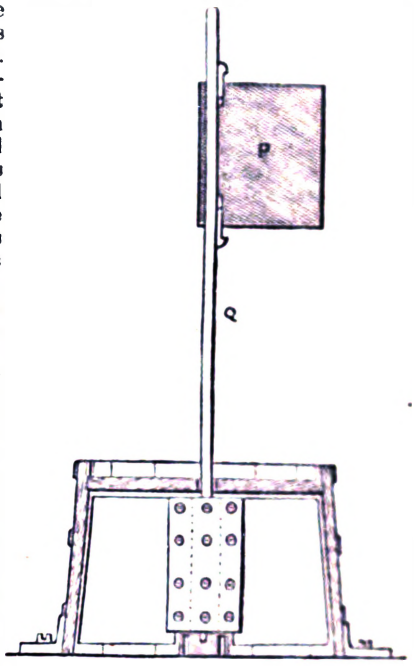
In experiment 87, resin-oil alone was used.

In experiments 90 and 91, water alone was used.

In experiment 92, resin-oil and a small stream of water were used.

A special apparatus was provided to indicate the direction in which the water left the wheel. For this purpose the vane P, Figs. 1271, 1275, 1276, was placed near the circumference of the wheel, and was keyed on to the vertical shaft Q, which turned freely on a step resting on the wheel-pit floor. The upper end of the shaft carried the hand R, Fig. 1271, and directly under the hand was placed the graduated semicircle S, divided into 180°. When the vane was parallel to a tangent to the circumference of the wheel, drawn through the point nearest to the axis of the vane, and the vane was in the direction of the motion of the wheel, the hand pointed at 0°, and, consequently, when the vane was in the direction of the radius of the wheel, the hand pointed at 90°. To prevent sudden vibrations of the vane, a modification of the *hydraulic regulator* was attached to the lower part of the vane-shaft. This apparatus is represented in detail by Figs. 1275, 1277.

1275.

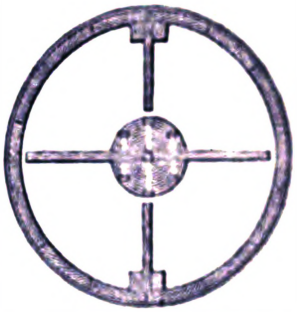



The quantity of water discharged by the wheel was gauged at a weir erected for the purpose at the mouth of the wheel-pit.

As the water issued from the orifices of the turbine with considerable force, particularly when the velocity of the wheel was much quicker or slower than that corresponding to the maximum coefficient of effect, there were often such violent commotions in the wheel-pit, that, unless some mode was adopted to diminish them before the water reached the weir, or even the place where the depths on the weir were measured, it would have been impossible to make a satisfactory gauge of the water. For this purpose a grating was placed across the wheel-pit. This grating presented numerous apertures, nearly uniformly distributed over its entire area, through which the water must pass. In the experiments with a full gate, the fall from the upper to the lower side of the grating was generally from 3 to 4 in. The combined effect of this fall and of the numerous small apertures was to obliterate almost entirely the whirls and commotions of the water above the grating. About 4·5 ft. in length of the grating was so nearly closed that but little water passed through that part of the grating; this made it very quiet in the vicinity of the gauge-box.

1276.

1277.



The weir consisted of two bays of nearly equal length; the crest of the weir was almost exactly horizontal, and the extreme variation did not exceed 0·01 in. The crest of the weir was of cast iron, planed on the upper edge, and also on the upstream face, to a point 1·125 in. below the top; below this there was a small bevel, also planed, the slope of which, on an average, was $\frac{3}{16}$ in. in a height of $\frac{5}{8}$ in.; the remainder of the casting was unplaned. The crest of the weir was $\frac{3}{8}$ in. thick, and was horizontal. The upstream edge was a sharp corner. The ends of the weir were of wood, and of the same form as the crest, except that there was no bevelled part. The crest of the weir was about 6·5 ft. above the floor of the wheel-pit. The ends of the weir projected from the walls of the wheel-pit, and also from the central pier, a mean distance of 1·235 ft. The length of one bay was 8·489 ft., and of the other 8 491 ft., making the total length of the weir 16 98 ft.

The depth of the water on the weir was taken in a gauge-box by means of the hook-gauge L, which is represented in detail in Figs. 1278 to 1280.

The hook-gauge is the invention of Boyden, and is an instrument of inestimable value in hydraulic experiments. In 'Versuche über den ausfluss des wassers durch schieber, hahne, klappen und ventile,' by Julius Weisbach, Leipzig, 1842, page 1, is described an instrument for observing heights of water, having a slight resemblance to the hook-gauge; it was, however, used by Boyden in a more perfect form several years previous to the publication of that work. All other known methods of measuring the heights of the surface of still water are seriously incommoded by the effects of capillary attraction; this instrument, on the contrary, owes its extraordinary precision to that phenomenon. The point of the hook A, Fig. 1279, is represented as

coinciding with the surface of the water. If the point of the hook should be a very little above the surface, the water in the immediate vicinity of the hook would, by capillary attraction, be elevated with it, causing a distortion in the reflection of the light from the surface of the water. The most convenient method of observing with this instrument is, first, to lower the point of the hook, by means of the screw, to a little distance below the surface; then to raise it again slowly, by the same means, until the distortion of the reflection begins to show itself; then to make a slight movement of the screw in the opposite direction, so as just to cause the distortion to disappear; the point will then be almost exactly at the level of the surface.

With no particular arrangements for directing light on the surface, differences in height of 0·001 ft. are very distinct quantities; but by special arrangements for light and vision, differences of 0·0001 ft. might be easily appreciated.

As this instrument cannot be efficiently used in a current, it was placed in a box in which the communication with the exterior was maintained by a hole, when, by partially obstructing this communication, the extent of the oscillations could be diminished at will.

For very exact observations it is essential that the surface of the water should be at rest. If, however, it should oscillate a little, a good mean may be obtained by adjusting the point of the hook to a height at which it will be visible above the surface of the water only half the time.

The movable rod to which the hook was attached was of copper, and graduated to hundredths of feet, but by means of the *vernier* thousandths were measured, and in some cases ten thousandths were estimated. In later and more perfect forms of this instrument, the point of the hook is immediately under the graduation.

The heights of the water in the fore-bay and in the wheel-pit were taken by means of gauges, placed in the gauge-boxes. Both gauges were graduated to feet and hundredths, and both had the same zero-point, namely, the level of the crest of the weir, so that the difference in the readings at the two gauges gave at once the fall acting upon the wheel; and the difference between the depths of the water on the weir, as observed at the hook-gauge, and the reading at the gauge, gave the fall at the grating.

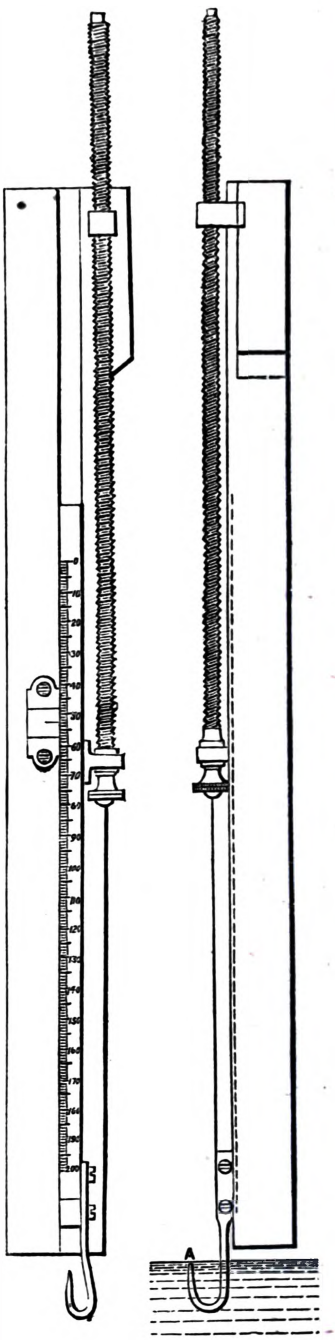
The heights of the regulating-gate were taken at the rack. The weights used for measuring the useful effect were pieces of pig-iron of various sizes, each of which had been distinctly marked with its weight.

*Mode of Conducting the Experiments.*—A separate observer was appointed to note each class of data; the time of each observation was also noted, which gave the means of identifying simultaneous observations. To accomplish this, each observer was furnished with a watch having a second-hand; the watch by which the speed of the wheel was observed was taken as the standard; all the others were frequently compared with it, and when the variations exceeded ten or fifteen seconds they were either adjusted to the standard, or the difference noted.

This mode of observing must, evidently, lead to more precise results than that in which a single observer, however skilful, undertakes to note all the phenomena, or even several of them. By the method adopted a regular record is made of the state of things at very short intervals, furnishing the data for a mean result for any required period, and also the means of detecting, in most cases, the causes of apparent discrepancies. It also relieves the experimenter from the distraction of having numerous exact observations to make in a very short time, and leaves him much more at liberty to exercise a vigilant watch over the general course of the experiment.

As it may be useful to experimenters not accustomed to this mode of observing, and at the same time afford the reader some means of judging of the accuracy of the results obtained in these experiments, the following extracts are given from the original note-books. The extracts include the data observed for experiment numbered 30 in Table II. (see TURBINE WATER-WHEEL). This experiment is selected simply because it gave the maximum coefficient of effect.

1278. 1279.




1280.

### Weight in the Scale.

| | lbs. | oz. |
|---|---|---|
| | 1498 | 10½ |
| 4h 43′ added .. .. .. .. .. .. .. .. .. .. | 26 | 0½ |
| Weight for the next experiment .. .. .. .. | 1524 | 10½ |

### Speed of the Wheel.

| Times at which the Bell struck. | | | Differences. | Times at which the Bell struck. | | | Differences. | Times at which the Bell struck. | | | Differences. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | sec. | hrs. | min. | sec. | sec. | hrs. | min. | sec. | sec. |
| 4 | 55 | 58·00 | | 5 | 0 | 52·00 | 59·00 | 5 | 4 | 47·00 | 59·00 |
| | 56 | 56·50 | 58·50 | | 1 | 50·75 | 58·75 | | 5 | 45·50 | 58·50 |
| | 57 | 55·25 | 58·75 | | 2 | 49·50 | 58·75 | | 6 | 44·25 | 58·75 |
| | 58 | 54·25 | 59·00 | | 3 | 48·00 | 58·50 | | 7 | 43·00 | 58·75 |
| | 59 | 53·00 | 58·75 | | | | | | | | |

The bell struck once in every fifty revolutions of the wheel.

### Elevation of the Pointer on the Bell-Crank.

| Time. | | | Height of Pointer, in Feet. | Time. | | | Height of Pointer, in Feet. | Time. | | | Height of Pointer, in Feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | | hrs. | min. | sec. | | hrs. | min. | sec. | |
| 4 | 55 | 0 | 0·19 | 4 | 59 | 30 | 0·20 | 5 | 4 | 0 | 0·17 |
| | | 30 | 0·13 | 5 | 0 | 0 | 0·18 | | | 30 | 0·18 |
| | 56 | | 0·13 | | | 30 | 0·19 | | 5 | | 0·24 |
| | | 30 | 0·14 | | 1 | | 0·21 | | | 30 | 0·18 |
| | 57 | | 0·15 | | | 30 | 0·17 | | 6 | | 0·19 |
| | | 30 | 0·19 | | 2 | | 0·20 | | | 30 | 0·19 |
| | 58 | | 0·20 | | | 30 | 0·19 | | 7 | | 0·16 |
| | | 30 | 0·19 | | 3 | | 0·19 | | | 30 | 0·14 |
| | 59 | | 0·21 | | | 30 | 0·19 | | | | |

The extremity of the pointer was 6·5 ft. from the fulcrum of the bell-crank. When the horizontal arms of the bell-crank were level, the height of the pointer was 0·20 ft.

### Height of the Water above the Wheel.

| Time. | | | Height, in Feet. | Time. | | | Height, in Feet. | Time. | | | Height, in Feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | | hrs. | min. | sec. | | hrs. | min. | sec. | |
| 4 | 55 | 0 | 15·100 | 4 | 59 | 30 | 15·110 | 5 | 4 | 0 | 15·120 |
| | | 30 | 15·100 | 5 | 0 | | 15·115 | | | 30 | 15·120 |
| | 56 | | 15·100 | | | 30 | 15·120 | | 5 | | 15·120 |
| | | 30 | 15·100 | | 1 | | 15·120 | | | 30 | 15·115 |
| | 57 | | 15·110 | | | 30 | 15·110 | | 6 | | 15·115 |
| | | 30 | 15·115 | | 2 | | 15·105 | | | 30 | 15·110 |
| | 58 | | 15·110 | | | 30 | 15·100 | | 7 | | 15·110 |
| | | 30 | 15·100 | | 3 | | 15·115 | | | 30 | 15·110 |
| | 59 | | 15·105 | | | 30 | 15·125 | | | | |

The top of the weir is the zero-point of the gauge in the fore-bay.

### Height of the Water after passing the Wheel.

| Time. | | | Height, in Feet. | Time. | | | Height, in Feet. | Time. | | | Height, in Feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | | hrs. | min. | sec. | | hrs. | min. | sec. | |
| 4 | 56 | 0 | 2·20 | 5 | 0 | 0 | 2·21 | 5 | 4 | 0 | 2·22 |
| | | 30 | 2·21 | | | 30 | 2·21 | | | 30 | 2·21 |
| | 57 | | 2·21 | | 1 | | 2·21 | | 5 | | 2·21 |
| | | 30 | 2·21 | | | 30 | 2·21 | | | 30 | 2·21 |
| | 58 | | 2·21 | | 2 | | 2·21 | | 6 | | 2·21 |
| | | 30 | 2·21 | | | 30 | 2·21 | | | 30 | 2·20 |
| | 59 | | 2·20 | | 3 | | 2·20 | | 7 | | 2·22 |
| | | 30 | 2·21 | | | 30 | 2·20 | | | 30 | 2·20 |

The top of the weir is the zero-point of the gauge in the wheel-pit.

HEIGHT OF THE WATER ABOVE THE WEIR BY THE HOOK-GAUGE.

| Time. | | | Height, in Feet. | Time. | | | Height, in Feet. | Time. | | | Height, in Feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | | hrs. | min. | sec. | | hrs. | min. | sec. | |
| 4 | 57 | 5 | 1·8710 | 5 | 1 | 10 | 1·8690 | 5 | 4 | 35 | 1·8730 |
| | 58 | 15 | 1·8710 | | 1 | 45 | 1·8700 | | 5 | 50 | 1·8725 |
| | 58 | 50 | 1·8720 | | 2 | 15 | 1·8720 | | 6 | 25 | 1·8725 |
| | 59 | 20 | 1·8730 | | 2 | 50 | 1·8720 | | 6 | 55 | 1·8725 |
| | 59 | 50 | 1·8715 | | 3 | 15 | 1·8715 | | 7 | 20 | 1·8720 |
| 5 | 0 | 15 | 1·8715 | | 3 | 40 | 1·8715 | | 7 | 45 | 1·8715 |
| | 0 | 45 | 1·8705 | | 4 | 5 | 1·8730 | | | | |

The zero of the hook-gauge was 0·002 ft. *below* the top of the weir.

DIRECTION OF THE WATER LEAVING THE WHEEL.

| Time. | | | Direction. | | Time. | | | Direction. | | Time. | | | Direction. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hrs. | min. | sec. | ° | ′ | hrs. | min. | sec. | ° | ′ | hrs. | min. | sec. | ° | ′ |
| 4 | 57 | 0 | 59 | 0 | 5 | 1 | 0 | 57 | 0 | 5 | 5 | 0 | 58 | 0 |
| | | 30 | 57 | 0 | | | 30 | 59 | 30 | | | 30 | 59 | 30 |
| | 58 | | 59 | 0 | | 2 | | 58 | 0 | | 6 | | 59 | 30 |
| | | 30 | 58 | 0 | | | 30 | 57 | 0 | | | 30 | 57 | 0 |
| | 59 | | 58 | 0 | | 3 | | 60 | 0 | | 7 | | 59 | 0 |
| | | 30 | 58 | 30 | | | 30 | 58 | 0 | | | 30 | 57 | 30 |
| 5 | 0 | | 57 | 0 | | 4 | | 59 | 0 | | 8 | | 59 | 0 |
| | | 30 | 57 | 30 | | | 30 | 56 | 0 | | | | | |

When the vane pointed in the direction of the radius of the wheel, the reading of the index was 90°. 0° was in the direction of the motion of the wheel.

Previous to the commencement of the experiments, the apparatus for measuring the useful effect was carefully adjusted. The bell-crank was balanced when there were no weights in the scale. For this purpose the link M, Fig. 1273, was removed, and the chamber of the hydraulic regulator filled with water; weights were then applied to the top of the bell-crank, near the end to which the hydraulic regulator was attached, until the whole was in equilibrium, the final adjustment was made, by placing a weight of about 2 lbs. at the extremity of one of the horizontal arms of the bell-crank,—the arm was retained horizontally until a signal was given, when it was left at liberty to descend, and the time occupied in descending a certain distance was noted; the weight was then removed to the extremity of the other arm, and the same process repeated. The balance-weights were altered until the times of descent were equal. To overcome as much as possible the friction of the fulcrum, the pin forming it was lubricated with sperm-oil, and during the descent the head of the pin was struck lightly and rapidly with a small hammer.

After the bell-crank was satisfactorily balanced, the link M was reattached, and the brake adjusted by means of the screw which formed the connection between the link and the brake. It was adjusted so that a line upon the brake was perpendicular to the axis of the link, when the horizontal arm of the bell-crank was horizontal. The length of the brake was then measured upon this line.

| | Feet. |
|---|---|
| The length of the brake as thus measured was found to be .. .. | 9·745 |
| The effective length of the vertical arm of the bell-crank was .. | 4·500 |
| And the effective length of the horizontal arm to which the scale was hung, was .. .. .. .. .. .. .. .. .. .. .. | 5·000 |

Consequently, the effective length of the brake was $\frac{9{\cdot}745 \times 5}{4{\cdot}5} = 10{\cdot}827778$

The gauges in the fore-bay and in the wheel-pit were carefully adjusted by levelling from the top of the weir. This was repeated by different persons, so as to remove all chance of error.

The Hook-gauge was compared with the weir by a different method. When the regulating-gate of the turbine was shut down as tight as possible, it was still found that a quantity of water leaked into the wheel-pit, exceeding, a little, the quantity that leaked out of the wheel-pit, so that a small quantity continued to run over the weir. The principal leak into the wheel-pit was between the regulating-gate and the lower curb, the leather packing not being perfectly adjusted. The Hook-gauge was firmly attached to a post, placed in the wheel-pit for that purpose, and at a height known to be nearly correct. The regulating-gate was closed, and after the water had arrived at a uniform state, the height of the water at the Hook-gauge was noted, and, at the same time, the depths of the water on the weir were measured directly with a graduated rule. To perform this accurately, a board, about 4 in. long, was held by an assistant on the crest of the weir, at the place where it was intended to measure the depth; the author then applied the rule, previously well dried, vertically, on the top of the weir, in front of the board. On first immersing the rule, the water in contact with it did not stand at the true level of the surface, but formed a little hollow around the rule; it immediately commenced rising, however, and after a few moments came to a level, which was indicated by the reflection of a light from the surface, a lamp being held by an assistant, in a proper position, for that purpose.

The depths on the weir, taken in the manner just described, February 20, 1851, were as follows:—

| | Depths on the westerly Bay of the Weir. inches. | Depths on the easterly Bay of the Weir. inches. |
|---|---|---|
| | 0·37 | 0·36 |
| | 0·36 | 0·36 |
| | 0·37 | 0·36 |
| | 0·37 | 0·36 |
| Means .. .. | 0·3675 | 0·36 |
| Or in feet .. | 0·0306 | 0·0300 |

While the heights given in the preceding Table were being measured, the depth by the Hook-gauge was constantly 0·0318 ft. consequently, by this comparison, the zero of the Hook-gauge was 0·0012 ft. below the mean height of the top of the weir, in the westerly bay, and 0·0018 ft. below the mean height in the easterly bay, or 0·0015 ft. below the mean height in both bays. A similar comparison was made February 22, 1851, when the zero of the Hook-gauge was found to be 0·0024 ft. below the mean height of the weir. The mean of the two comparisons, or 0·0020, was adopted as the correction to be subtracted from the reading of the Hook-gauge, to give the mean depth upon the weir.

During the experiments, the levels of the water in the upper and lower canals were maintained nearly uniform. The height of the lower canal, at the place where the water, passing the weir, fell into it, varied a little, depending upon the quantity of water discharged by the wheel. It was highest when the wheel was running with the regulating-gate fully raised, and the brake removed; under these circumstances the surface of the water was from 0·3 ft. to 0·4 ft. below the top of the weir. In the other experiments with the regulating-gate fully raised, the fall from the top of the weir to the surface of the water in the lower canal was from 0·4 ft. to 0·6 ft. The brackets and the planks were not put on until after the turbine experiments were concluded, so that the water passing the weir met with no obstruction until it struck the water in the lower canal.

The obstruction caused by the planks was scarcely appreciable, which renders it certain that the effect of the lower canal, in obstructing the flow over the weir, must have been entirely inappreciable.

*Emerson's Dynamometer-Brake.*—A reliable dynamometer-brake, like that of James Emerson, Fig. 1281, which would show the amount of power transmitted at all times and under all circumstances, is a useful instrument. When the object is merely to ascertain the amount absorbed or required by a single machine, a series of machines, or a line of shafting, or the necessary means of transmitting power, a temporary attachment of the power-measurer, Fig. 1281, will be sufficient: but there are cases where a permanent attachment of the device is desirable. Such are all cases where the users of mechanical power are hirers, and pay so much for each horse-power used. The method of guessing or averaging, based on width of belt, size of pulleys, and weight of shafting, is hardly accurate enough where the cost of production of power is felt, as where the power is supplied from a steam-engine, or a water source liable to diminish in amount, or fail entirely. The dynamometer-brake should also be so simple in construction, and so exact in operation, as to be readily understood, and afford no possible or justifiable cause for controversy between hirer and letter of power. Such is the design of the device of Emerson.

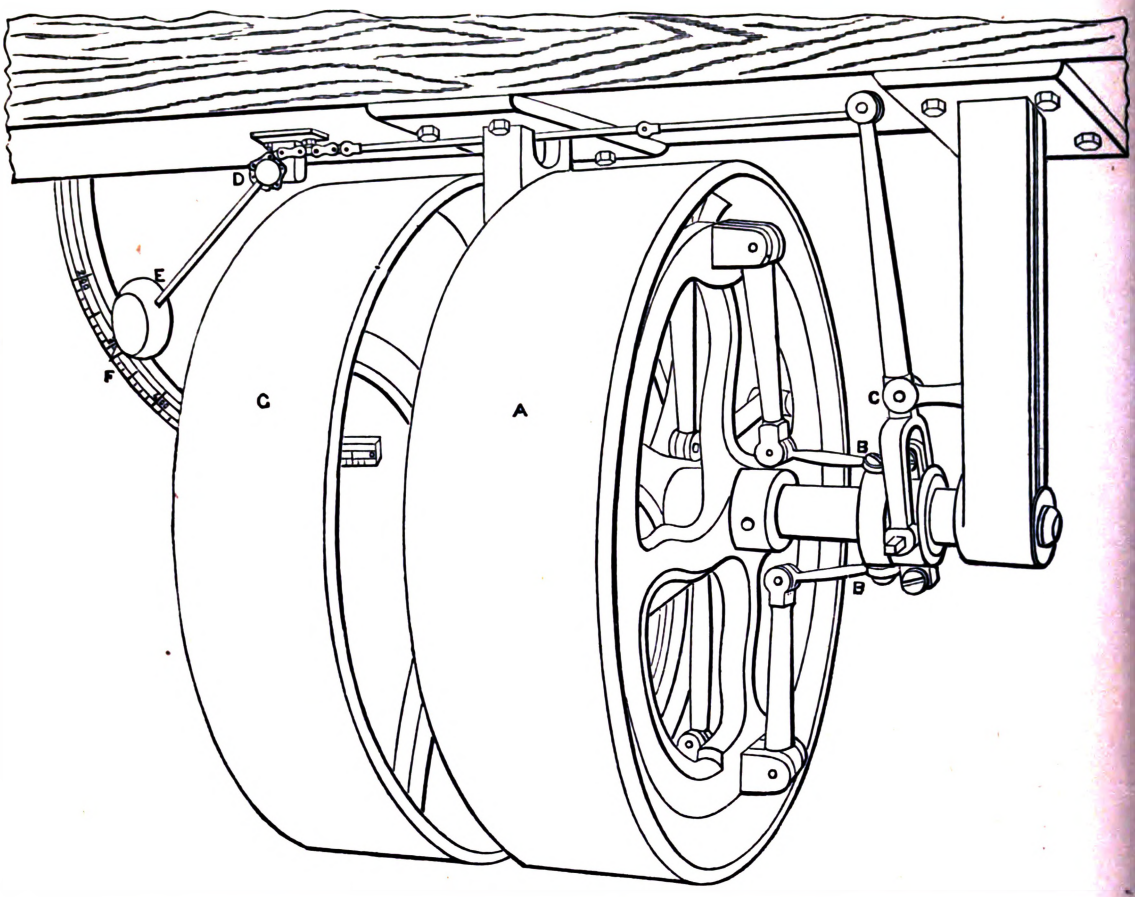
It is very simple in construction, and direct in operation. The pulley A is loose on the shaft, and receives the power. Its connection with the shaft is made by means of a wheel, keyed or screwed firmly to the shaft in close contiguity with the receiving pulley, its hub, in fact, forming one of the guides to the position of the pulley on the shaft. To connect this fixed wheel with the loose receiving pulley, a bell-crank lever is pivoted into projecting ears on the rim of the fixed wheel on opposite sides, the long arm of which connects with an annular slotted collar on the shaft by means of the short bars B. The short arms of the bell-crank levers connect on the inside of the fixed wheel with two radial bars, one parallel to the outer arm of the bell-crank, and the other at right angles to it, receiving near its upper end a pivot passing through a swivel hung to the rim of the fixed wheel, and having its extreme end pivoted to a stud fixed on the inner side of the rim of the receiving pulley. It will be seen from this description that the strain of the power received through the belt on A will necessarily react on the levers, and, through them, on the fixed wheel, which may be considered nothing more nor less than a support to these levers in sustaining them in position to connect the loose receiving pulley with the shaft.

At B it will be seen the levers are connected by pivots with the sliding collar, in the annular groove of which is seated a strap with which is connected a forked lever, the fulcrum at C. To the end of the long arm of this lever a rod with a short section of machine chain is attached. This chain runs over the cylindrical head D of a pendulum weight E, having a pointer that traverses a fixed quadrant F, properly divided by a scale to denote the relative pressure exerted through the medium of the receiving pulley on the shaft. The pulley G is fixed to the shaft, and delivers the power.

It will be seen that all the motions are absolute, there being no chance for play and back-lash, except that of joints and pivots; and this by good workmanship, can be reduced to the minimum—too little to be taken into consideration practically. There is no dependence upon springs, spiral, or other forms, which are so liable to be affected by changes of temperature, and so unreliable between extremes of demand. It is a weighing machine as correct in principle as the old-fashioned steelyards or the platform-scales; in fact, it is simply a rotary platform-scale, and each machine may be weighed and tested in place by hanging to the pulley A sealed weights,

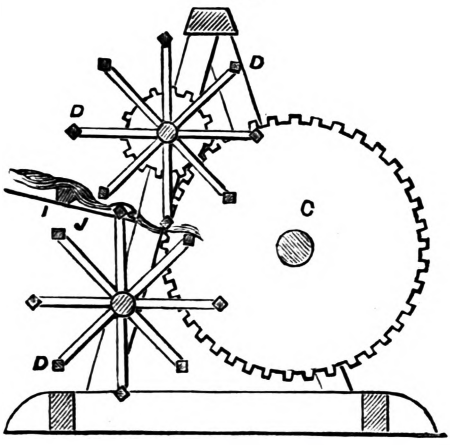
and marking the index as each weight is added. The lengths of the connecting-bars and chain are adjustable. The machine may be made of different sizes, and in different styles, suitable for testing all kinds of machinery. One kind especially adapted for spinning-frames, looms, &c.; another to be connected by belt to a line of shafting, or any kind of machine. And one especially adapted for testing turbine water-wheels, to which it is easily applied, with but comparative small expense.

1281.

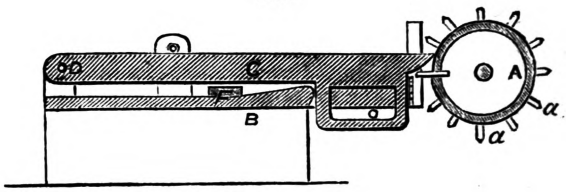



John F. Gilman's *Hemp-Brake* has an adjustable cross-rail I, Fig. 1282, secured to two inclined arms J arranged in front of the revolving beaters D in such a manner as to admit of the cross-rail being adjusted higher or lower when the hemp is passed over it on its passage to the beaters; the beaters being operated by means of the cog-wheel C.

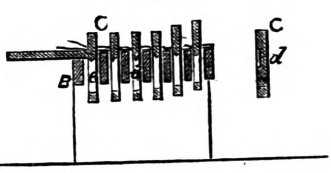
1282.




1283.




1284.




In the Flax and Hemp Brake of A. W. Hall, Figs. 1283, 1284, a bar F underlies all the beaters C, and by means of a lever-handle may be turned up edgewise to raise all the beaters evenly when

desired. The beaters, provided with openings C, knives and cutters *d*, and saws *e*, are operated by means of pins *a* placed in one or more spiral rows on a cylinder A in connection with the slotted bed B, and a suitable spring or springs, all arranged so that the beaters will work consecutively in pairs and perform the operations of braking, scutching and feeding simultaneously. The knives *d* and saws *e* are attached to a few only of the beaters on the discharge side of the machine to cut the flax or hemp, and also to separate the fibre from the woody portion, and divide it into finer threads.

1285.

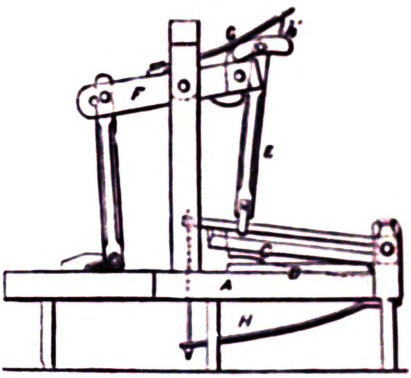



Fig. 1285 shows J. Bryant's Hemp and Flax Brake. A is the frame, B the bed, and H the treadle. The beater C is operated in such a manner that in the event of its being impeded by tough hemp or flax, it may yield, and thus avoid undue straining. To this end the rod E, which connects this water with the working-beam F, is pivoted at its upper end to a zig-zag bar *h'*, which has a limited range of motion on a pivot which secures it to the beam. A strong spring G upon the top of the beam bears constantly on the zig-zag bar to hold it quite rigidly, but yet allow it and the beater to yield slightly when necessary.

See Agricultural Implements. Belts. Dynamometer. Friction. Gearing. Governor.

BRANDERING. Fr., *Revêtir les solives de voliges*; Ger., *Beschalen*; Ital., *Listellare un soffitto.*

*Brandering* is the covering of the under-side of joists with battens about 1 in. square in the section, and 12 to 14 in. apart, to nail the laths to, in order to secure a better key for the plaster of a ceiling.

BRAN-SEPARATOR. Fr., *Dodinage*; Ger., *Kleisieb*; Ital., *Frullone*; Span., *Cedazo muy abierto.*

See Barn Machinery, p. 228, Figs. 544, 545.

BRASS. Fr., *Laiton, Cuivre jaune*; Ger., *Messing*; Ital., *Ottone*; Span., *Azófar, Laton.*

See Alloys, Antimony, Bismuth, Copper, Lead, Tin, Zinc. Aluminium, Arsenic, Manganese.

BRAZING COPPER. Fr., *Soudure de laiton*; Ger., *Hartlöthen*; Ital., *Saldare il rame.*

See Tin and Copper Plate Working.

BRAZING SOLDERS. Fr., *Soudures*; Ger., *Löthmittel*; Ital., *Saldatura forte*; Span., *Soldaduras.*

See Soldering.

BREAKWATER. Fr., *Brise-flots, Brise-lames*; Ger., *Wellenbrecher*; Ital., *Molo, Diga di difesa, Pennello.*

A breakwater is a kind of sea-wall or artificial embankment, formed of large stones, and erected for the purpose of protecting the entrances of harbours and roadsteads from the injurious effects of violent winds, by breaking the force of the sea; the shipping moored behind them lying perfectly secure. A breakwater differs from a bulwark in having water at both sides of it. In determining the site of a breakwater, it should be so chosen as to present a barrier to the waves of the prevailing storms, and especially to those which come along the flood-current. It may be isolated, and built in the entrance of a bay, as is the case at Plymouth and Cherbourg; or it may run out from the shore into deep water. In the latter case, the best position for the junction of a single breakwater with the land is generally at the up-stream corner of the entrance to the inlet or harbour, for in that position the breakwater opposes the strongest flood-current, and does not materially interfere with the weakest ebb-current. The front of the work should have that part below low-water mark with a deeper slope than that above, as being less violently acted on by the waves; for instance, from 1-1 to 3-1 below, and from 4-1 to 7-1 above. The waves will partially break and lose their energy in passing over the place where the inclination changes. The back of a vertical-pointed breakwater is usually also vertical; that of a sloping or combined breakwater, if intended to be used as a quay, is vertical; in other cases it only differs from the front in having a steeper slope and being faced with smaller blocks.

The breakwater in Delaware Bay was designed not only to form an artificial roadstead, sheltered from the effects of the prevailing winds, but also from the drift-ice brought down occasionally in large quantities from the upper part of the Schuylkill and Delaware rivers.

The transverse section of the breakwater was made as follows:—The inner slope towards the harbour was formed at an angle of 45° with the horizon; the top was made 30 feet wide, and at 5 ft. 4 in. above the level of the highest spring tides. The outer slope was carried down, with an inclination of 3 base to 1 in height, to a depth of about 19 ft. from the highest spring tides, and from thence to the bottom at an angle of 45°. The mass of the work between the sea bottom and a horizontal place, passing at 6 ft. below the lowest spring tides, was formed of stones weighing from ¼ to 2 tons, and the slopes covered with blocks of from 2 to 3 tons minimum weight. Between this point and the plane corresponding with the lowest spring tides, the body of the work was executed in stones weighing from ¼ to 2½ tons, protected externally by blocks weighing 3 tons each at least; and the upper portion was formed exclusively of blocks weighing from 4 to 5 tons, laid as regularly as possible, the slopes being covered with the largest blocks, laid as headers.

See Dam. Harbour.

BREAD MACHINE. Fr., *Machine de boulangerie;* Ger., *Backmaschine;* Ital., *Macchina da far il pane;* Span., *Máquina paria fabricar el pan.*

Bread and Biscuit Machinery.

The process of bread-making is closely connected with that of fermentation. Wheaten flour consists, essentially, of starch and gluten, combined with a small portion of dextrine and sugar. The tenacity of *bread-dough* is due to the gluten present in the flour; the dough being produced by simply mixing the flour with a little water.

If bread-dough be tied up in a piece of fine muslin, and kneaded under a stream of water, the starch will be suspended in the water, having passed through the muslin; the gluten remains as a tough elastic mass, which soon putrefies if exposed to the air in a moist state, and dries up to a brittle horny mass at the temperature of 212° Fahr. Gluten is a compound substance, and is found to contain carbon, hydrogen, nitrogen, and oxygen, in the proportions, nearly, of 24, 20, 3, and 7 respectively.

When gluten is boiled in alcohol, a portion of it refuses to dissolve; this portion is termed *vegetable fibrine.* When this dissolved matter and alcohol are allowed to cool, a white flocculent substance, similar to the *caseine* which composes the curd of milk, is deposited. On adding water to this cold solution, the *glutine* is separated, which resembles the albumen found in considerable quantities in the blood. Although *gluten* presents three substances similar to the three principal components of the animal body, yet gluten separated from the flour by the process just described would be found very difficult to digest, on account of its resistance to the solvent action of the fluids in the stomach; for it is well known that *bread-dough*, composed of flour and water, even when baked, is indigestible. In order to render bread-dough fit for food, it must be rendered spongy, that is, porous, so as to expose a larger surface to the action of the digesting fluids; the most direct method of effecting this is the one adopted in the manufacture of *aërated bread*, which consists in mixing the flour with water that is highly charged, under pressure, with carbonic acid gas; the mixing by this method is effected in a closed iron vessel, an aperture in the lower part of which is opened, then the pressure of the accumulated gas forces the dough out of the strong iron vessel into the air; the gas which has been confined in the dough expands and gives porosity and sponginess to the dough.

Another process for preparing *unfermented bread* consists in mixing the flour with a little bi-carbonate of soda; this mixture is then made into dough with water acidulated with hydrochloric acid; the bread is thus rendered porous. The chloride of sodium, formed at the same time, remains in the bread. In the making of cakes and pastry, the same object is attained by adding carbonate of ammonia to the dough. When baking, the salt is converted into vapour which distends the dough.

The tenacity of gluten, even in wheaten flour, is liable to variation; and in order to obtain good bread from a flour the gluten of which is inferior in this respect, it is customary to employ a small quantity of alum. This addition being considered unwholesome, it would be better to substitute lime-water, which has been found by Liebig to have a similar effect. Sulphate of copper improves in a very striking manner the quality of the bread prepared from inferior flour, but this salt is far more dangerous than alum.

Wheaten flour is particularly well fitted for the preparation of bread on account of the great tenacity of its gluten. Next to wheat, with respect to glutinous capacity, stands rye; whilst the other cereals contain a gluten so deficient in tenacity that they cannot be converted into good bread.

In the ordinary process of bread-making, the carbonic acid that confers sponginess upon the dough is evolved by the fermentation of the sugar contained in the flour; the flour having been kneaded with the proper proportion, usually about half its weight, of water, a little yeast and salt are added, and the mixture is allowed to stand at a temperature of about 70° Fahr. for some hours. The dough swells or *rises* considerably, in consequence of the escape of carbonic acid, the sugar being decomposed into that gas and alcohol, as in ordinary fermentation. The spongy dough is then baked in an oven, heated to about 500° Fahr., when a portion of the water and all the alcohol are expelled, the carbonic acid being, at the same time, much expanded by the heat, and the porosity of the bread increased. The granules of starch are much altered by the heat, and become more digestible. Although the temperature of the inside of a loaf does not exceed 212° Fahr., the outer portion becomes dry and hard, the hottest part being scorched into crust.

Instead of yeast, *leaven* is often employed, in order to ferment the sugar: leaven is a name given to dough which has been left in a warm place until decomposition has commenced.

The passage of new into stale bread does not depend, as was formerly supposed, upon the drying of the bread consequent upon its exposure to air, but is a true molecular transformation which takes place equally well in an air-tight vessel, and without any loss of weight. It is well known that when a thick slice of stale bread is toasted, which *dries* it still further, the crumb again becomes soft and spongy as in new bread; and if a stale loaf be placed in an oven, it is reconverted into bread resembling new.

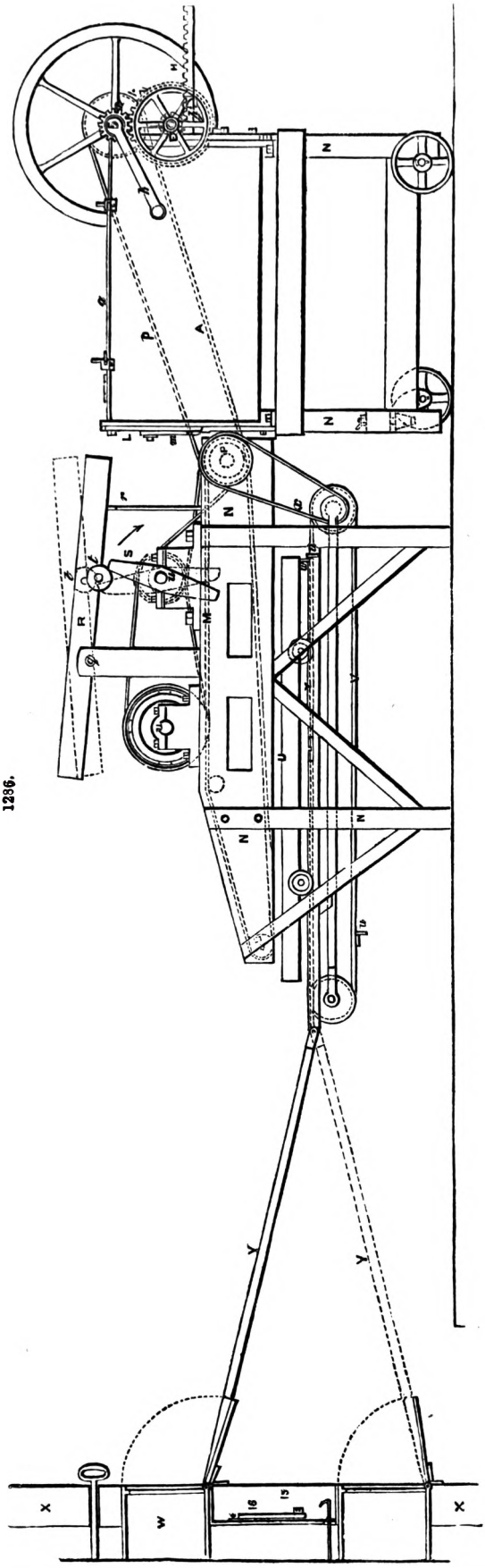
With William Watson's bread-making apparatus, Figs. 1286 to 1292, the entire operation, from the mixing of the flour and the other ingredients to the final deposit of the dough in the oven for baking, is performed by machinery.

The mixer consists of a horizontal cylinder, with flanges at each end, and a door at the upper part, throughout its length, for introducing the materials, and through which the agitator or stirrer of the mixer may be removed. The cylinder is supported on suitable feet, and at one end is enclosed for about a third of its diameter by a fixed plate, which descends below the flange, and forms the base or foot at that end; the upper two-thirds of the cylinder end is closed by a sluice-door, which can be raised as required to form an opening for the exit of the dough. The other end of the cylinder is fitted with a piston, which forms a close end for the cylinder during

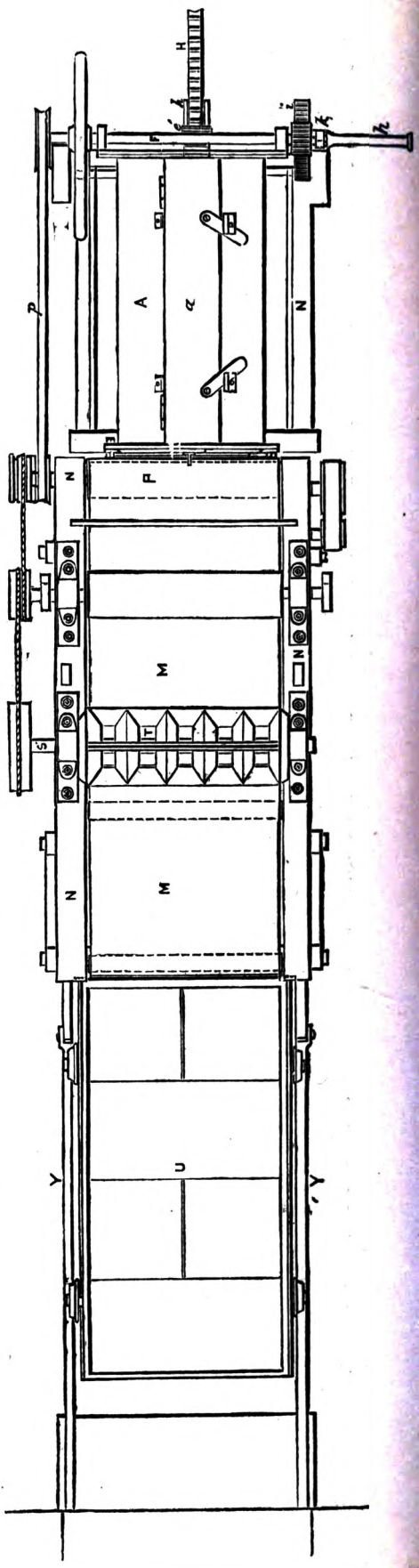
the mixing; this piston can be traversed in the cylinder, in which it fits sufficiently tight for the expulsion of the dough. An opening is made in the piston for the passage of an axis to carry the agitator of the mixer, which axis is carried by a bearing supported by a bracket from the flange of the cylindrical chamber; the axis at the other end passes through an opening in the sluice-door fitted with a bearing fixed thereto, or the bearing may be separately supported from the flange of the cylinder. The agitator of the mixer is made of a zig-zag kind of form, occupying the diameter of the cylinder, the several limbs of which extend across the diameter of the cylinder, and are all in the same plane, the angles at the extremities being all right angles, or nearly so. It has no central axis passing through it, being supported by a short axis at each end fitting into square holes in the extreme limbs of the agitator, which increase much in strength at those points. In order to strengthen and bind the several radial limbs or blades together, tie-rods are disposed in the direction of the axis, but distant about one-third the radius from the centre. The absence of the central axis prevents the dough collecting in the centre of motion. The limbs are inclined on both sides in opposite directions on opposite sides of the axis, in the manner of a screw, so that in rotating the agitator it forces the dough from one end to the other of the mixer, and on being reversed carries it in the opposite direction. The agitator is dropped in edgewise by a tackle at the door above, the ends of the cylinder being so adjusted that the bosses of the end limbs of the agitator bear hard against the ends and make the axis-holes dough-tight; the end limbs are also in close proximity to the ends, in order to scrape the adhering dough from them. The flour, water, and other ingredients having been emptied into the mixer, motion is communicated to the agitator by winch-handles at either end on the axis, or by means of a wheel and pinion. The dough having been mixed, the agitator and its axis are removed, and a long rack placed in the piston resting in a bearing, substituted for the axis-bearing, which is removed; a pinion is disposed to take into the rack, the axis of which pinion is carried by bearings on the flange, and if the machine is small, may be driven by crank-handles on the pinion axis, but if large, a multiplying toothed gear and fly-wheel shaft is used, by communicating motion to which the piston will be forced forwards by the rack, and the dough expressed as required; the same fly-wheel may also be made otherwise available when removed by placing it on the axis of the agitator. The sluice-door opens by means of a hand-lever, and is so adjusted as to emit the desired thickness of plastic dough, which is of a width proportionate to the size of the machine. The dough, when expressed, is received on an endless cloth moving on rollers and other supports, which is speeded to travel at the same rate as the expressed dough; in emerging, the dough passes under a duster, a perforated box containing flour receiving a lifting and dropping motion from a cam acting on a lever carrying such box; it then passes under a smooth roller, which smooths and reduces the dough to a uniform thickness, and under two or three rollers, if necessary. The thickness of dough which is sufficient for the substance of a loaf then passes under a rotating dividing cylinder, consisting of a series of dividing discs placed on a shaft; these discs are thick in the centre, but thinned towards the edge at the periphery, and present somewhat of a V form in a cross-section taken from the centre to the circumference; these discs are disposed on the shaft at distances apart, according to the size of the loaf to be made; there are also dividing edges placed between the discs, parallel with the shaft, separating the circumference into equal parts, which are two, three, or more in number, according to the size of the loaves to be formed and also to the diameter of the divider itself. This divider is driven at a speed uniform with the endless cloth, down upon which it presses and divides the plastic dough into loaves. It does not actually cut the dough, the dividing edges being rounded, but simply presses sufficiently deep creases in it to produce the subsequent separation required; thus the breadth of dough is cut up into a greater or less number of loaves, according to its breadth: after passing under the divider the divided dough passes from the endless cloth on to trucks to be conveyed into the oven. The cloth turns backwards under its carrying roller, from under which the trucks are pushed forwards at same rate as the dough travels, and these move on rails up to the oven-mouth. The cloth dips a little at the delivery end, and turns back under a very small roller, so that the drop of the dough on to the truck is very slight, and all moving at same speed it is readily carried away uninterruptedly as it is made, and the truck or car, which may or may not be of the length of the oven, is pushed forward on the sole until it occupies its position therein.

The oven is constructed of two, three, four, or more chambers, one above another, each of the width of dough delivered by the machinery; these chambers are of cast or wrought iron, placed between two brick walls, running from end to end of the oven, above the one chamber and below the other; the flues traverse from end to end, the longitudinal flues communicating alternately at opposite ends, so that the mouths of the several baking chambers or ovens are alternately at opposite ends, and must be filled in opposite directions. The fire and first flue is immediately under the chamber, and is considerably narrower than the chamber, in order to modify the heat; the succeeding and upper flues are wider than the lower one, but still considerably less than the width of the chambers, in order to prevent excess of heat at the sides near the brick walls, which would otherwise be apt to burn the bread at each side. When one chamber is full, the truck-carrying rails are shifted to a higher one, and the next truck is carried into the next chamber above, and so on until all the ovens are filled and the full batch delivered. Between the fire and lower flue and the first chamber is a cold-air flue, which protects the chamber from the immediate heat of the fire; the cold air traversing therein is admitted to the fire near the door, and supplies it with air with the door or blower closed, and so keeps the bakehouse cool. The trucks or cars consist simply of two parallel angle-irons, disposed and braced together at a sufficient breadth, and mounted on four or more wheels. The bottoms of the trucks are made of tiles or metal plates, which may have any given pattern, so as to impart an impression to the bottoms of the loaves placed thereon. The ovens are closed by doors that fall down and form a sole or stock-plate in front; the door being jointed to the sole of the door-frame in the manner of a butt-hinge, forms a close joint both with the door closed, and a level surface with the sole of the oven when open

1236.




1237.



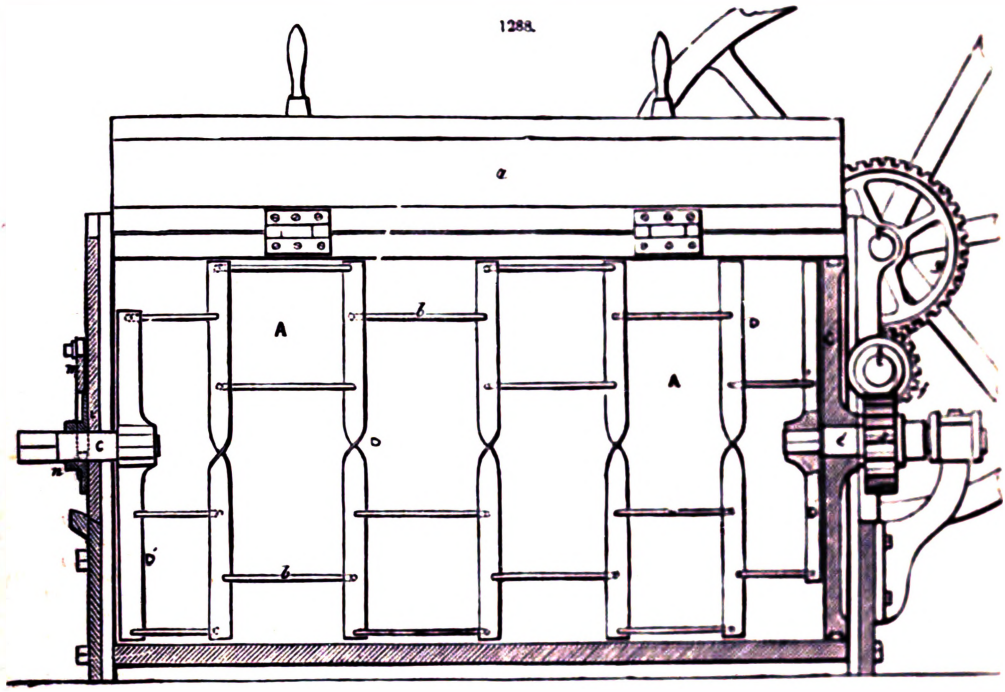
When baked, the bread is withdrawn from the oven, and may be broken asunder and handled and distributed as usual.

Watson, also, adapts this mixer to what is termed the expansion system of baking, that is, mixing the yeast with a small portion of the dough first, and such first portion with a larger portion, and so on. For this purpose an agitator is employed with a through axis and screw, and fixed radial arms therein, which have bevelled sides.

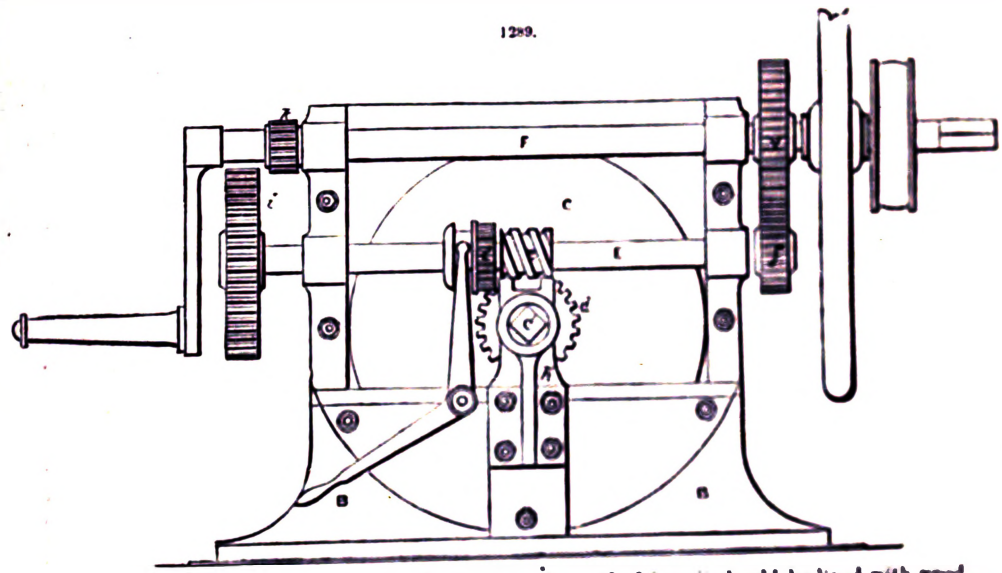
Fig. 1286 is a side elevation of this machine, which exhibits the arrangement of the one usually employed; Fig. 1287 represents a plan of the same with the dusting-box removed; while Figs. 1288 to 1292 represent some of the parts detached.

Fig. 1288 is a vertical longitudinal section of the mixing and expressing vessel; Fig. 1289 is an end view of the same at the end from which it is driven.

1288.

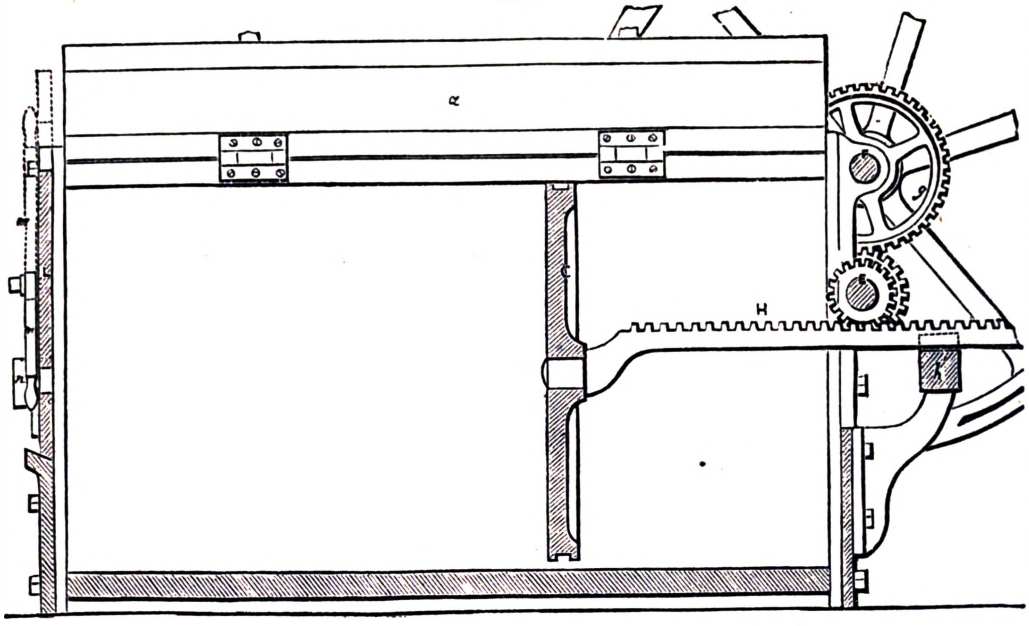



1289.

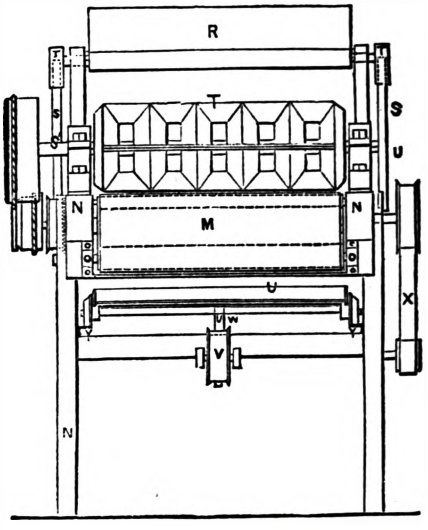



A is the cylinder or containing vessel of wood or iron; if of iron it should be lined with wood. It is mounted on feet or standards B, B, and is furnished with a hinged lid or cover a. C is the piston, which forms one end of the mixer, the other end being fitted with a sluice-door for allowing the dough to pass out. The agitator or mixer properly so called is formed of a series of pieces of iron united together by means of stays b, b. The pieces D, D, are twisted in opposite directions

1290.




1291.

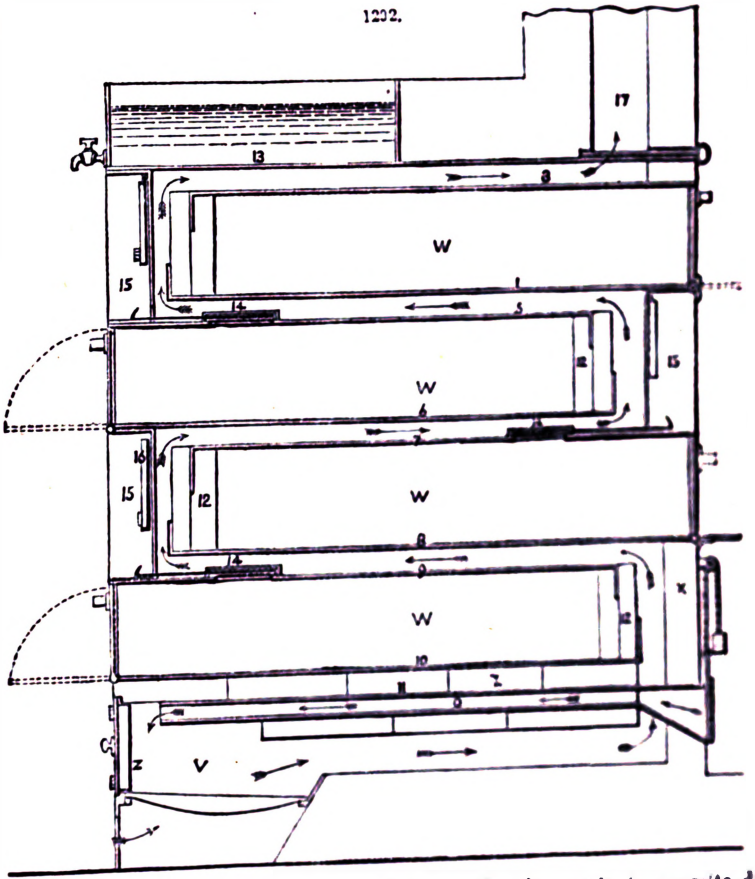



from the centre of motion so as to form inclines or screw surfaces, which in rotating have a tendency to force the material on which they are operating in one direction, that is to say, towards the end of the vessel; the end limbs D′ D are somewhat stronger than the others, and have bosses with holes in which short shafts *c*, *c′* are inserted from either end, and motion being communicated to which causes the rotation of the mixer To transmit the motion a screw wheel or pinion *d* is fixed on the shaft *c′* this gears into an endless screw *e* fixed on cross-shaft E. On this shaft is fixed a pinion *f* gearing into wheel *g*, mounted on the main shaft F, which may be driven by a winch-handle *h* or otherwise. The ingredients having been placed in the mixer, and mixed and treated as before described to form dough and bread, and after allowing sufficient time for the dough to rise, it is forced out of the chamber A in the following manner:—We remove the short shafts *c*, *c′*, from the agitator D, D, and lift it out of chamber A, and then close and fix the lid *a*. A rack H, Fig. 1290, is now placed in the piston C, which it fits into and rests in a crutch-bearing *h′*, formed on the top of the outside bearing of shaft *c′*. The pinion *d* is fitted to slide on shaft *c′*, but to carry it round with it by means of a feather. To communicate motion to the piston C, the shaft E is moved in the direction of its length, which has the effect of throwing a pinion *e′* fixed thereon into gear with the rack H, and at same time throwing pinion *f* out of gear with wheel *g*, and wheel *i* into gear with pinion *k*, which reduces the speed of rotation of shaft E, and the pinion *e′* taking into rack H, imparts to it a longitudinal motion, and forces the piston C from its position at one end of the cylinder A towards the other end, and thereby compressing the dough in that chamber. To allow the dough to escape at the other end of the cylinder A, the sluice-door L is lifted up by a lever *m* to either of the dotted positions *m*, shown, the first being suitable for the formation, say, of 2-lb. loaves, and the second for 4-lb. loaves. The gland of bearing *n* of the shaft *c* is previously removed, and a solid plate substituted for it to prevent the dough being forced out thereat. The sluice-door L being lifted and fixed, say, at the lowest position, the dough contained in A by the pressure of the piston C will be forced out of the entire breadth of the opening of the sluice-door, and of regulated thickness, which will be contained in one uniform substance so long as any dough remains in the chamber A. From this chamber the dough is received on an endless web M, carried on rollers P and P′, mounted on a suitable framework N, N. The endless web M is further supported by a table Q, extending under the entire breadth, supporting the weight of the dough, which forms a continuous slab, so to speak. It travels at a uniform rate, the endless cloth M being driven at the same rate of speed as the dough travels by its expulsion from the chamber A. The cloth M is driven by a strap-pulley fixed on the axis of P and strap *p*, communicating with a rigger on the main driving-shaft E, and in its backward course underneath is rubbed in a tray containing flour to prevent the dough adhering. After emerging from chamber A, and while travelling on M, the dough is submitted to a dusting

operation from a dusting-box R, mounted above on a fulcrum *q*. This box or tray is the breadth of the dough, and has a perforated bottom. It contains flour, and preponderates on its fulcrum so as to fall against a stop or rest *r*. It is agitated by means of a double arm S, mounted on a rotating axis *u*, the arms coming in contact with a truck-roller *t*, mounted on the side of the dusting-box R. The axis *u* is driven by a strap from a rigger on same axis as P and power is transmitted hereto by strap-riggers to an axis S', on which the divider T is mounted. This divider consists of a series of cutting ridges arranged in circular and longitudinal directions, the edges of which come down on the endless web, or nearly so. This divider is driven at about the same speed as the dough, which, on passing under it, becomes separated, or nearly so, into blocks of a given size, say, for 2-lb. loaves, which was the size before mentioned as arranged by the sluice-door L. If for larger loaves the mass of dough should be double the thickness, or another divider with larger cavities used. The several shafts are fitted in bearings in the framework N, and otherwise appointed, as shown in the figures. The divided dough, which is prevented sticking to the divider by the flour dredged on it, continues its course on the endless web M until it arrives at P'', where the divided dough Q is transferred to a truck U, disposed underneath in readiness for its reception. So soon as the dough begins to fall on to this truck, the truck also has a forward motion imparted to it, by a projection *u* on an endless strap *v* coming in contact with a projection *w* on the under-part of the truck. This endless strap is mounted on suitable pulleys, driven by a strap *x* from the axis of P''. The truck being mounted on wheels and suitable rails Y, travels along with its load towards the oven, which, as seen in the side view and plan, is immediately on end of the machine, so that as the truck is propelled forwards it enters the oven with its load of divided dough or loaves, and as the oven-chamber is by preference just the size to contain one truck, the oven-door is closed, and the baking proceeded with. Another truck is similarly disposed to receive the dough, and is carried forward into another chamber of the oven, and so on. The bottoms of the trucks, which are simply sheets of metal laid on the truck-frames, are roughened or indented, as seen in the plan, Fig. 1287, so as to imprint the bottoms of the loaves; they should also be dusted with flour to prevent the dough adhering. The rails Y are shifted for each oven-chamber, so as to rest on the door of each chamber, and conduct the truck to it. The truck having received its load of dough ceases to be propelled by the machine, but is pushed forward by hand into the oven, which is closed, and another one prepared with the rails to receive the next in succession.

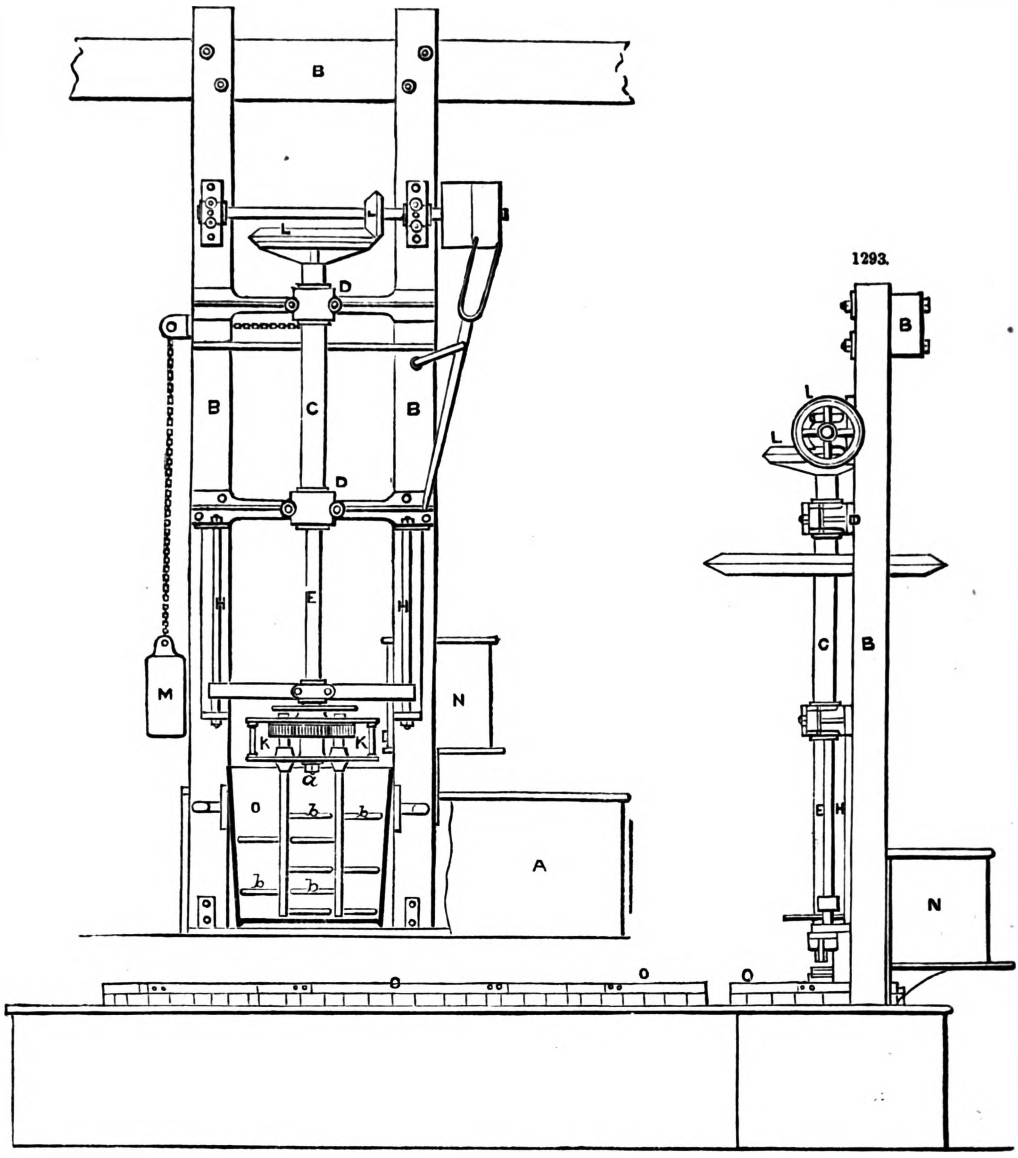
Fig. 1292 represents a longitudinal section of an oven used with Watson's machinery.

1292.




W, W, are the oven-chambers, which have their mouths alternately in opposite directions. They are formed between two brick walls X, X, the spaces being divided off by iron plates 3, 4, 5, to 11, the spaces between each pair of plates 3, 4, forming the flues to heat the oven-chambers, while below the plate 11 the furnace V is disposed. In order to protect the lower oven from the

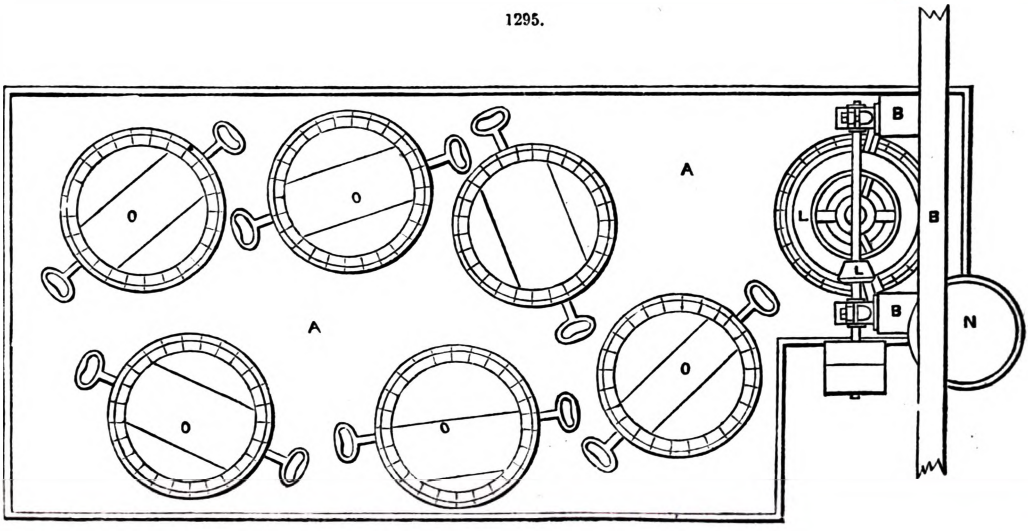
1294.




1293.




1295.



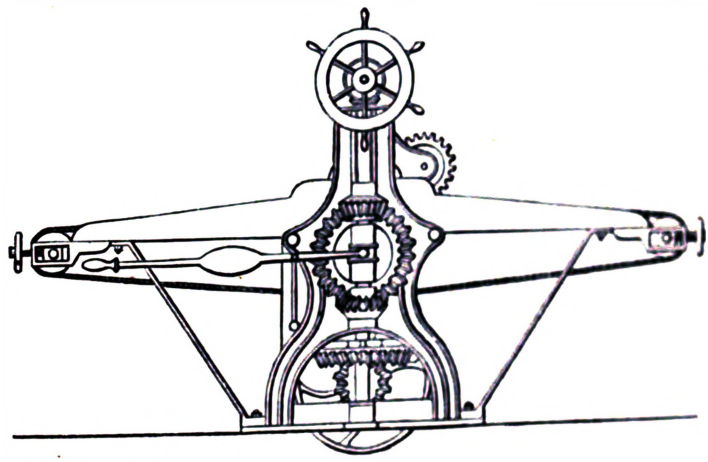
immediate heat of the furnace, plate 11 is covered with a thickness of brickwork, or it may be both above and below, as seen at *z*, *z*, with an air-flue *o* through the middle, and of equal width with the fire, or nearly so. Air enters at the back end of *o*, which is regulated as required by a sluice-door to limit the supply to the fire through that channel: a constant change of air taking place in this channel assists in preventing the direct heat of the furnace overheating the lower oven-chamber. Z is the furnace-door. The flue from the furnace passes up in two branches, one on each side of air-flue *o*, at the end of the lower oven-chamber, then along above it under the second chamber, thence passing up at the end, and back under the third oven-chamber, and so on. To prevent excessive heat at the end of the oven-chambers, fire-lumps, as seen at 12, 12, are used to protect them, the metal plates of the oven being so made as to hold them in position. 13 is a water-tank, to be heated from the waste-head for bakehouse purposes; 14 is a slide-valve in the top of each oven-chamber, enclosed in a case except at the end that is not opposed to the draught of the flues. These valves are opened by thumb-rods when it is desired to allow steam to escape from the ovens; 15, 15, are hollow box ends of metal, closing the ends of the flues, by removing which the smoke-flues may be easily cleaned. These boxes being open from the outside are convenient for the insertion of thermometers, as seen at 16, to see and ascertain the heat of the ovens at all times. The escape of the flues to the chimney is at 17.

*Vicar's Machinery employed in the Manufacture of Bread and Biscuits.*—Fig. 1293 represents a side elevation of a soft-dough mixing machine; Fig. 1294 a front elevation; and Fig. 1295 a ground plan. Fig. 1296 is a side elevation of a breaking machine, which is employed for preparing the dough for the moulding machine. Fig. 1297 is a sectional elevation through Fig. 1298, which represents a top plan view of the moulding machine; Fig. 1299 is an end elevation. Fig. 1300 is a front elevation of a machine employed for moulding or shaping the dough into loaves or biscuits; Fig. 1302 is a ground plan of the dough-shaping machine; Fig. 1301, a sectional elevation. Fig. 1303 is an end elevation of Fig. 1302 at C.

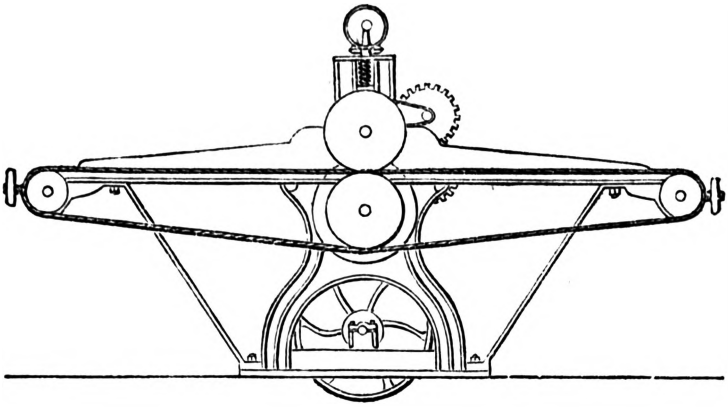
On Figs. 1293 to 1295, A, A, is a tank or reservoir capable of holding water; B, B, is a framework, to which are connected the following parts:—C, a hollow shaft working in bearings in the castings D, fixed to the framing B, E is a shaft capable of sliding in the shaft C, and of rotating therewith near the lower part of the shaft E; a cross-head G is connected and slides on guide-rods H. I is a skeleton framing mounted loosely upon the shaft E, and connected thereto by a nut at *a*, Fig. 1294; K, K, are spindles, the upper parts whereof work in bearings in the framing I. The lower parts of these spindles are formed with prongs *b*. *c*, *d*, *e*, are wheels gearing into each other, that marked *c* is fixed on the shaft E, and those marked *d* and *e* are respectively fixed on the spindles K, K; L, L, is bevel-gearing for imparting rotary motion to the shaft C. M, a counterbalance weight connected by a chain *f* to the lower end of the shaft E, to facilitate the raising of E; N is a vessel to contain water to mix with the flour; O, O, are vessels in which the dough is mixed.

The operations of this machine are as follows:—The operator takes the ferment or yeast commonly used, and instead of mixing it in a trough by hand, as commonly practised, he places the yeast or ferment and flour in one or other of the vessels O, and, placing same under the machine, lowers the prongs *b* thereinto, and proceeds to impart rotary motion thereto, the effect of which is to cause the wheels *c* to rotate the wheels *d* and *e*, and also the axes K, on which the prongs *b* are fixed, thus producing three distinct rotatory movements simultaneously, namely, one rotation of the framing I, which carries the wheels *d*, *e*, and the axes of the prongs K, and another rotation of each of the wheels and axes and prongs, thereby effectually mixing and incorporating the ingredients together into a sponge; and when this operation has been continued a sufficient length of time, according to the judgment of the operator, he removes the tub O from under the machine, and places it in another part of the vessel, and taking another tub charges it with yeast and flour as before, and proceeds in this manner with each tub in succession. When the sponge is sufficiently risen or fermented, the tub is again brought under the machine, and the required flour and water added to the sponge, and made by the machine into dough. The dough is then left to *prove*, and when sufficiently proved is removed to the machine, Figs. 1296 to 1299, there to

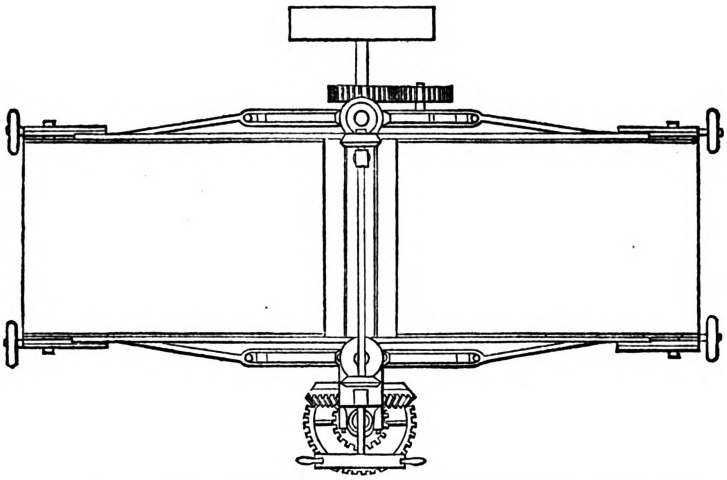
1296.



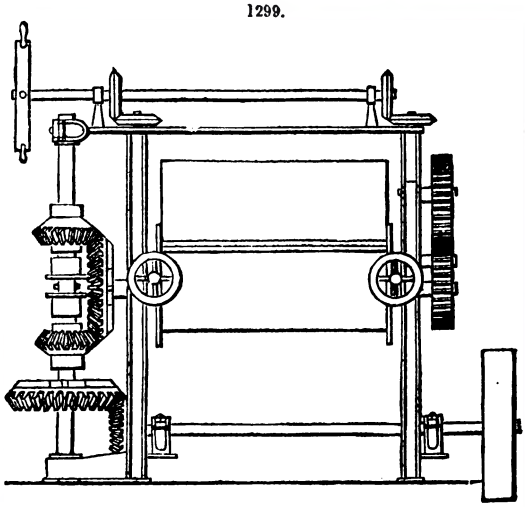
1297



1298.



1299.



be operated upon by the brake-rollers of this machine for the purpose of taking the proof out of the dough. As regards this machine, Figs. 1296 to 1299, it should be distinctly understood that its construction forms no part of the machine shown in Figs. 1293, 1294. Both machines are described in conjunction, for the purpose of completing the description of the machinery necessary to be used in manufacturing bread, biscuits, and like articles. When the dough has been sufficiently operated upon by the brake-rollers it is removed from this machine to the shaping machine, Figs. 1300 to 1303, and operated upon thereby in the manner presently described.

We would here remark, that the means above described which we propose to employ, and have found to answer well in practice, for ensuring the proper amount of fermentation forms a very important feature in this invention, for by the use of cold water in hot weather we are enabled to prevent excess of fermentation, and by employing warm water in cold weather we can induce fermentation, the temperature of the water being regulated according to circumstances and the judgment of the operator.

We now proceed to describe the operations of the moulding or shaping machine. With respect

to the three rollers, marked A, B, C, Figs 1300 to 1303, that marked A is employed to form the upper crust, and those marked B and C to form the lower crust, the soft dough being placed upon the table D, so as to pass with the two aforesaid crusts between the rollers E and F, by which the whole is compressed as the machine rotates, the endless travelling belt or web G advancing the dough under the moulding mechanism at H, where it is momentarily held still by the mechanism until the knives I descend and ascend by the action of the side rods K. The dough thus scored or shaped now passes onward by the action of the belt G, and when it comes under the stamps at L receives the impress therefrom of words, such as, for example, *machine-made bread*, this movement being simultaneous with the shaping movement with which it is connected: and in this manner the machine continues to mould and shape the dough into the form of loaves, which, as they are advanced forward by the endless belt or web G, are deposited on to trays, the trays being placed upon another endless belt or web N, the operation and construction of this part of the machinery and implements employed being as follows:—First, as regards the trays: they consist of flat pieces of wood, about 3 ft. by 2 ft., with ledges at the sides only thereof. Upon each of these trays is placed a piece of coarsely-woven cloth, and to each end thereof loops of tape, about 6 in. asunder, are affixed, and so as to project beyond the ends of the cloth about 2 or 3 inches, the loops being used for a purpose which will be described in another place. See OVENS. These trays, each with their respective cloth, are separately placed on the part M of the endless belt or web N, so that as this belt advances and comes under the part 1 of the belt or web G, the shaped

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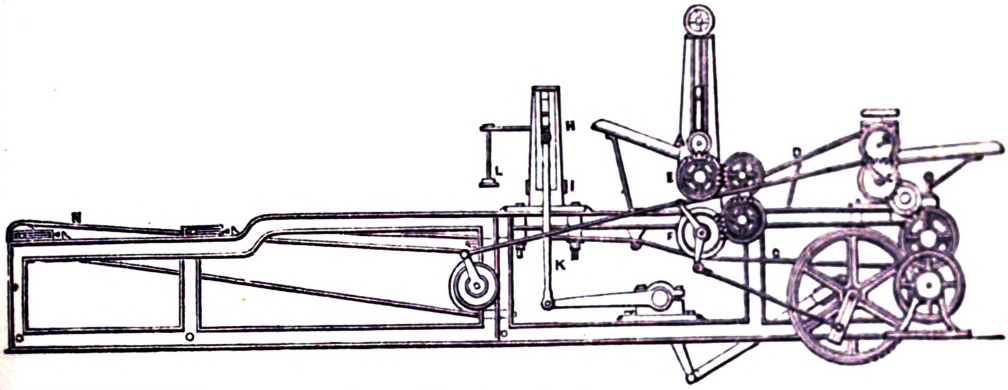


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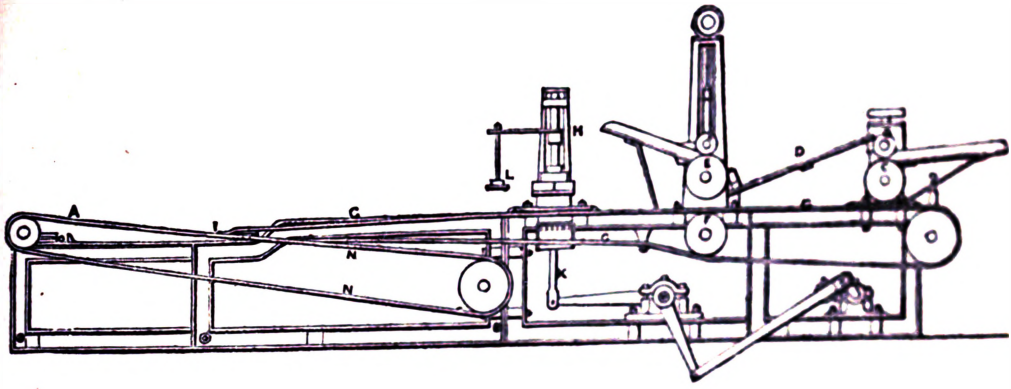


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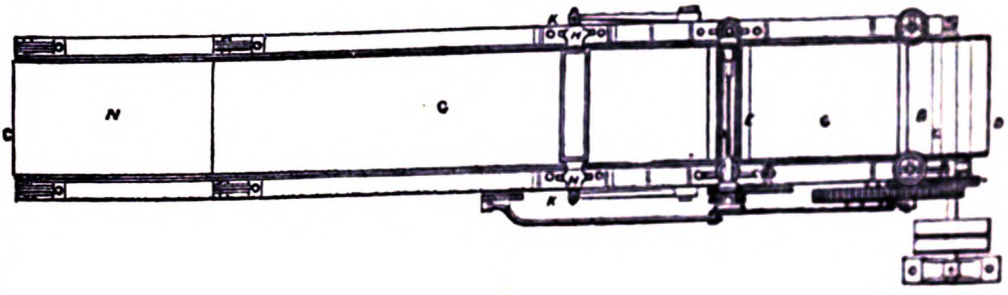

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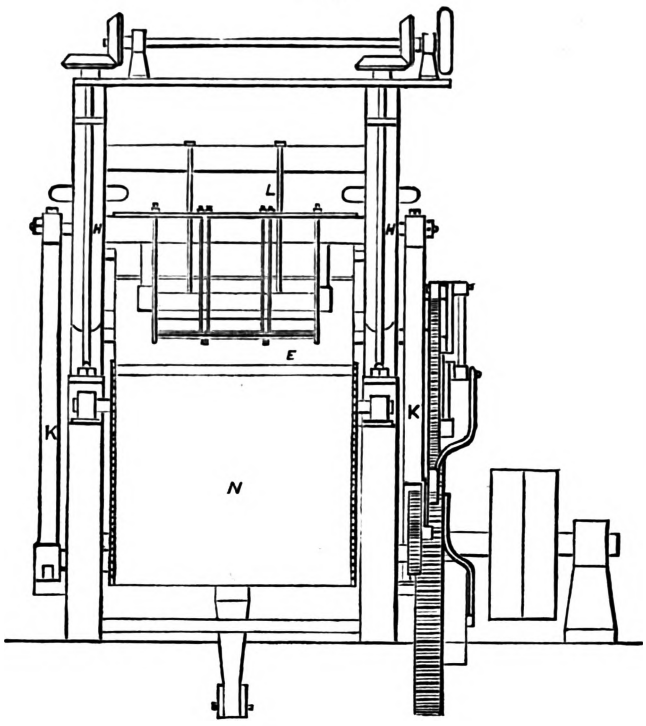



dough will be deposited on each of such said cloths and trays in succession, the operator dividing the dough when the tray is filled therewith; and in this manner several trays may be filled in succession.

See BARN MACHINERY. MILLS. MIXERS. OVENS. YEAST.

BREAKING JOINT. FR., *Joint de recouvrement;* GER., *Ueberdeckungsfuge, Deckfuge.*

*Breaking joint*, or *break joint*, is a term used in brickwork and masonry to express the arrangement by which the bricks or stones are made to overlap, the converse of which is termed "joint over joint." See BOND.

BREAKWATER. FR., *Brise-lames, Jetée;* GER., *Wellenbrecher;* ITAL., *Murazzo, Scogliera;* SPAN., *Muelle, Espolon.*

See HARBOURS. PIERS. SEA-WALLS.

BREAST-WALL. FR., *Mur de soutenement;* GER., *Schütemauer;* ITAL., *Muriccinolo.*

A *breast-wall* is a wall built up breast-high, as a parapet-wall or a *retaining wall*, placed at the foot only of a slope.

BREAST-WHEEL. FR., *Roue hydraulique de côté;* GER., *Kropf Rad, mittelschlächtiges Wasserrad;* ITAL., *Ruoto di fianco.*

See OVERSHOT WATER-WHEELS. UNDERSHOT WATER-WHEELS.

BREASTWORK. FR., *Fronteau;* GER., *Schott, Schotting;* ITAL., *Parapetto;* SPAN., *Repecho, Parapeto.*

See FORTIFICATION.

BREEZE. FR., *Breeze;* GER., *Lösche;* ITAL., *Bragia.*

The term breeze is applied to ashes and cinders used instead of coal in the burning of bricks.

BREEZE-OVEN. FR., *Four à Breeze;* GER., *Coaks Ofen;* ITAL., *Fornace da far arso.*

See OVENS.

BRESSUMMER. FR., *Sommier;* GER., *Unterzug;* ITAL., *Trave maestra;* SPAN., *Sotabanco.*

A bressummer is a beam placed breastwise to support a superincumbent wall; used principally over shop-windows to carry the upper part of the front, and supported on posts or columns.

BREWING APPARATUS. FR., *Machines de brasserie;* GER., *Braugeräthschaften;* ITAL., *Macchine ad utensili da birraio.*

In making beer, the brewer first *mashes* the ground malt with water of a temperature of 176° to 182° Fahr., when the *diastase*, or substance containing nitrogen, operates to convert the mass into dextrine and sugar. The greater part of the starch, which has not been changed during the germination, and the *wort*, or new unfermented beer, is ready to be drawn off to be converted into beer. Brewers' grains, or the undissolved part of the malt, is employed to feed cows and pigs, as it contains much gluten.

To find whether malt contains more diastase than is necessary to convert its starch into sugar, it is only necessary to add a little fusion of malt to the viscid solution of starch; when this compound is maintained at a temperature of 150° Fahr. for a few hours, and the diastase is in excess, the mixture will become far more fluid, and will no longer be coloured blue by solution of iodine.

Distillers take advantage of the excess of diastase in malt, by adding from two to four parts of

unmalted grain to the diastase, the whole of which becomes converted into dextrine and sugar, and thus the labour and expense of malting are avoided. The wort produced by infusing malt in water contains not only sugar, dextrine, and diastase, but a large quantity of nitrogenized matter formed with the gluten of the barley. Before subjecting the wort to fermentation, it is boiled with a quantity of hops, usually amounting to from $\frac{1}{20}$ to $\frac{1}{8}$ part of the weight of the malt employed. Hops are found to prevent the tendency of the beer to become sour: the sourness of beer is produced when the alcohol of the beer is converted into acetic acid. Hops contain from 9 to 10 per cent. of an aromatic yellow powder, termed *lupuline*, and is the active portion which contains a volatile oil of particular odour, together with a bitter substance. When the compound of wort and hops is run off into a vat, it is allowed to deposit the undissolved portion of the hops, then the clear liquor is drawn off into coolers, where the temperature of the compound is lowered as rapidly as possible to about from 58° to 61° Fahr.; the cooling is usually expedited by cold water circulating through pipes which traverse the coolers. When the wort is cooled too slowly, the nitrogenized matter which it contains undergoes a change from the action of the air, in consequence of which beer becomes acid. After cooling the mixture, it is placed in the *fermenting tun*, where the fermenting is carried on by adding *yeast*, which is about $\frac{1}{12}$ part of the compound.

It has been found, with the aid of the microscope, that *yeast* is a minute fungoid vegetable that grows in solutions containing sugar combined with particular nitrogenized substances, such, for instance, as a salt of ammonia, and the salts—phosphates of potash, soda, lime, and magnesia.

The conditions under which the yeast plant grows were not ascertained and scientifically examined until recently for a long time, after the growth of this substance was ascertained, the seeds or germs from which it originates eluded detection, although its growth resembles some of the lower mosses.

The process of brewing may be divided into four distinct stages:—1. The *malting*, of which the object is to produce in the barley the principle which effects the conversion of starch into dextrine and glucose, and which essentially consists in causing the barley to sprout under the influence of a proper temperature and degree of moisture, diastase being formed at the origin of the sprouts, and in the succeeding operation converting the starch into soluble dextrine and glucose. 2. The preparation of the *wort* (moût), or saccharification of the malt, which consists in treating the ground malt with water at a suitable temperature, in order to cause the diastase to act on the starch and dissolve the dextrine and glucose which result from this action. 3. The boiling with hops, which consists in heating the wort with hops in order to give it a peculiar taste and aroma. 4. Fermentation, which consists in mixing the cooled wort with a ferment, in order to effect the conversion of glucose into alcohol.

The barley is first placed in large vats of mason-work, with four times its volume of water, being stirred frequently to expel the bubbles of air between the grains, while those which arise on the surface, being generally defective, are skimmed off. The object of this process is chiefly to swell the grains, in order that they may sprout more easily; and it lasts 24 or 36 hours in winter, during which time the water is renewed three times; while in summer it requires only 10 or 12 hours, but the water must be renewed four or five times.

The barley thus swollen is carried to the malt house, a kind of cave or cellar, the floor of which must be kept scrupulously clean to avoid all injurious fermentations. Germination requires the assistance of moisture, air, and a temperature of from 50° to 62°, which conditions are most readily realized in spring or autumn; whence the name of *March beer* is given to that made in the spring, and is considered superior to that made in any other season. In the malt house the barley is spread in a layer of about 1½ ft. in depth, and thus left until it becomes heated, but when it begins to sprout, the thickness of the layer is reduced to 1 ft., and then to 3 in. when the germination approaches the proper point. It is also frequently stirred, in order to renew the air in the interior of the layer. In the hot season, the germination is terminated in 10 or 12 days, while it requires 15 or 20 days toward the close of autumn, the sprout having then become two-thirds as long as the grain.

When the barley has properly sprouted, it is dried rapidly, in order to arrest the loss of the amylaceous matter which would ensue from a longer growth of the sprout and radicles. The drying is first made in the open air, by spreading the grain over the floor of a well-aired granary, and then in a stove traversed by a current of hot air, and called a *malt kiln*. Desiccation renders the radicles of the barley very brittle, but they are easily removed by sifting them in a *winnowing machine* or *fan*. The sprouted barley, thus freed from the radicles, is exposed for some time to the air, when it imbibes a small quantity of moisture, which facilitates its grinding. This operation is effected between horizontal stones, kept at such a distance from each other that the grain is broken and torn without being reduced to flour. The product is *malt*, which is stowed away for future use.

The saccharification of the malt is effected in large wooden vats, having a double bottom pierced with holes, intended to support the barley and facilitate the introduction and escape of the liquid. In the space between the two bottoms are the discharging-tube and one which conveys hot water. When the malt is placed in the vat, water at 140°, and equal in weight to one and a half times that of the malt, is poured in, the mixture being actively stirred with a kind of fork. It is then allowed to rest for half an hour, until the malt is thoroughly moistened, when water at 190° is added, until the temperature of the mixture attains 167°, which is the most favourable for saccharification; after which it is again stirred, the vat covered, and the reaction allowed to continue for three hours. The saccharine fluid, or *wort*, is then conveyed into a reservoir, and thence into the boilers intended for the decoction of hops.

As the first digestion with water only abstracts from the malt 0·6 of the saccharine matter it can furnish, an additional quantity of water at 176° is added, equal to one-half of that used in the

first operation, and is allowed to act for one hour, the liquid produced being added to the first. Lastly, the malt is exhausted by water at 212°, and a liquid obtained which is used in making small-beer. The exhausted malt (called, in this country, *grains*) is used as food for animals.

The wort is heated to ebullition with hops in boilers, which must be kept covered to prevent the escape of the essential oil, to which beer owes its aroma, and are furnished with an apparatus which constantly stirs the mixture. The strength of the wort is sometimes increased by the addition of glucose, molasses, or raw sugar. The wort, thus hopped, is conveyed into reservoirs, where it is clarified by rest, and then run off into other reservoirs, where it is cooled as rapidly as possible, by allowing the liquid layer only a thickness of 4 or 5 in.; the cooling vats being placed in large rooms surrounded by Venetian blinds, in order to afford a free circulation of air. The proportion of hops is about 1 kilogramme for every hectolitre of table-beer, and 2 kilogrammes for every hectolitre of strong beer.

When the wort is cooled, it is poured into a *fermenting vat* or *tun*, and a quantity of yeast added, varying, according to the season and strength of the wort, from 2 to 4 kilogrammes for every 1000 litres, and maintained at a temperature of about 68°. The fermenting house should be well aired, in order to allow the carbonic acid to pass off rapidly. The fermentation lasts from 24 to 48 hours, producing a large quantity of froth, which falls from the tun into spouts arranged for the purpose, and which, when collected and expressed in bags, constitutes *beer-yeast*.

The tuns are always kept full by adding the liquid separated from the froth. The fermentation of table-beer is completed in small casks filled to the bung, and placed on a scaffolding over a spout which carries off the froth still arising from the liquor; and when the fermentation is finished the kegs are plugged, and the beer only requires a clarification with fish-glue.

Strong beer is allowed to ferment slowly for several weeks after the fermentation in the tun, in large vats, holding as much as 2600 gallons.

See ATTEMPERATOR. BARLEY-DRESSING MACHINE. COOLERS. DISTILLING APPARATUS. ELEVATORS. FERMENTATION. GRAIN MEASURER. HOP BACK. KILN. LIQUOR BOILER. MALT-DRESSING MACHINE. MALT HOUSE. MALT MILL. MALT SCREEN. MASHING MILL. MASH TUN. REFRIGERATOR. SPARGER. STOVES. UNION CASKS. WORT COPPER. YEAST.

BRICK-MAKING MACHINES. FR., *Machine de briqueterie;* GER., *Ziegelpresse;* ITAL., *Macchina da far mattoni.*

The Brick-making, Pugging, and Crushing Machine of H. Clayton, Son, and Howlett, is shown in Fig. 1304. The clay to be made into bricks is thrown into the hopper A of the machine. In this hopper revolves a shaft on which are keyed several small knives, which cut up the clay previous to its being crushed. It next passes through the crushing-rollers B, B, which effectually reduce to powder any stones or hard lumps of clay that may enter the hopper A.

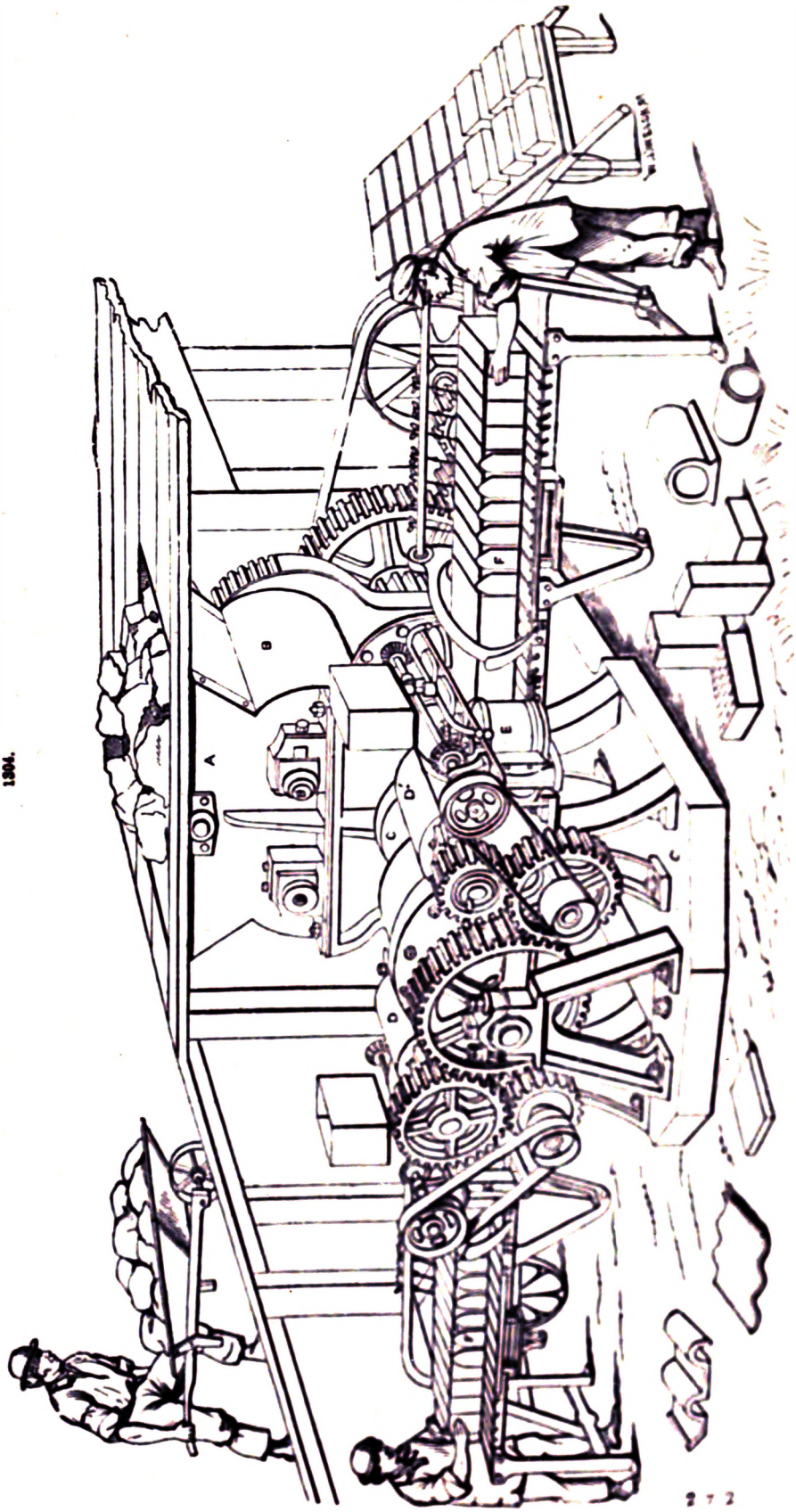
The clay, thus partially prepared, next passes into the horizontal pug-cylinder C, where it is thoroughly mixed and incorporated by the pug-knives which are fixed upon the central shaft These knives are so placed that they force the clay towards the farther end of the cylinder, where it is pushed by means of a rotary blade or piston, and taken by the small feeding-rollers D, D'. The mixture having been drawn by the small feeding-rollers D, D', into the chambers, which are placed before the dies E, E, situated one on each side of the machine, the brick material issues through the rotary orifice dies in a smooth and regular stream, the angles well formed and the surfaces clean. It is then cut into bricks, of the required size, upon the cutting-tables F, F. This construction of machine is made of two sizes, and requires no masonry foundations, the whole being fixed upon cast-iron foundation-plates G.

The larger machines are worked by a 16-H.P. engine, and each is capable of producing from 20,000 to 30,000 bricks a day, varying according to the quality of clay used.

The smaller machine is generally worked by a 10-H.P. engine; this machine is capable of producing from 15,000 to 20,000 bricks a day.

In ordinary hand-made bricks, the main expense of the process of making, besides the burning, consists in the preparation of the clay, so as to render it sufficiently ductile to allow of its being forced into the moulds by hand-pressure; this necessitates the mixing of water with it, and thus requires also the further process of drying the bricks before placing them in the kiln. The risk of damage and the delay from weather also add materially to the expense of hand-made bricks. The application of machinery to the manufacture of bricks has for its objects economy, certainty, and expedition of production, and improvement in the quality and appearance of the bricks. It is still a question how far these objects have been attained; and out of the large number of machines invented for brick-making, but few are at present in regular work; omitting *tile and pipe-making machines*. The machines now at work may be divided into two classes—those which operate upon the clay in a moist and plastic state, and those for which the material requires to be dried and ground previous to being moulded. In the former class, the plastic column of clay, having been formed in a continuous length by the operation of a screw, pugging-blades, or rollers, is divided into bricks by means of wires moved across, either whilst the clay is at rest, or whilst in motion by the wires being moved obliquely at an angle to compensate for the speed at which the clay travels. In consequence of the clay having to be made sufficiently soft to allow of this wire-cutting, the bricks made are but little harder than those made by hand, and require similar drying before being placed in the kiln; and this drying, together with the expense of preparing the clay in the requisite manner, renders the expenses of manufacture similar to those involved in hand-made bricks. In the second class of machines, a superior finish of appearance is obtained in the bricks by their compression in a dry state in the mould, and the objection of subsequent drying is avoided: but the additional preparation requisite in drying the clay and reducing it to a sufficiently fine and uniformly pulverized state, and the more expensive character of the machinery involved, add materially to the cost of manufacture.

By means of the brick-making machine invented by a Mr. Oates, and described by John E. Clift in a paper read before the Inst. of Mechanical Engineers, the difficulty of previous prepara-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tion of the clay required in the second class of machines is not incurred; while at the same time the subsequent drying of the bricks required with the other machines is avoided. In this machine the clay is used of such a degree of dryness as to allow of its being mixed up and macerated and compressed into bricks by a single continuous action; the clay being formed into a continuous column and compressed into the moulds by the action of a revolving vertical screw. The clay requires generally no previous preparation beyond that given by the ordinary crushing-rollers, and is sometimes ready to be put into the machine direct from the pit; in other cases, where containing a mixture of stones, it is first passed through a pair of crushing-rollers.

The machine is shown in Figs. 1305 to 1311. Fig. 1305 is an end elevation of the machine; Fig. 1306 is a front elevation, and Fig. 1307 a plan; Fig. 1308 is a vertical transverse section enlarged; Fig. 1309 a plan of the screw, and Fig. 1310 is a longitudinal section of the machine.

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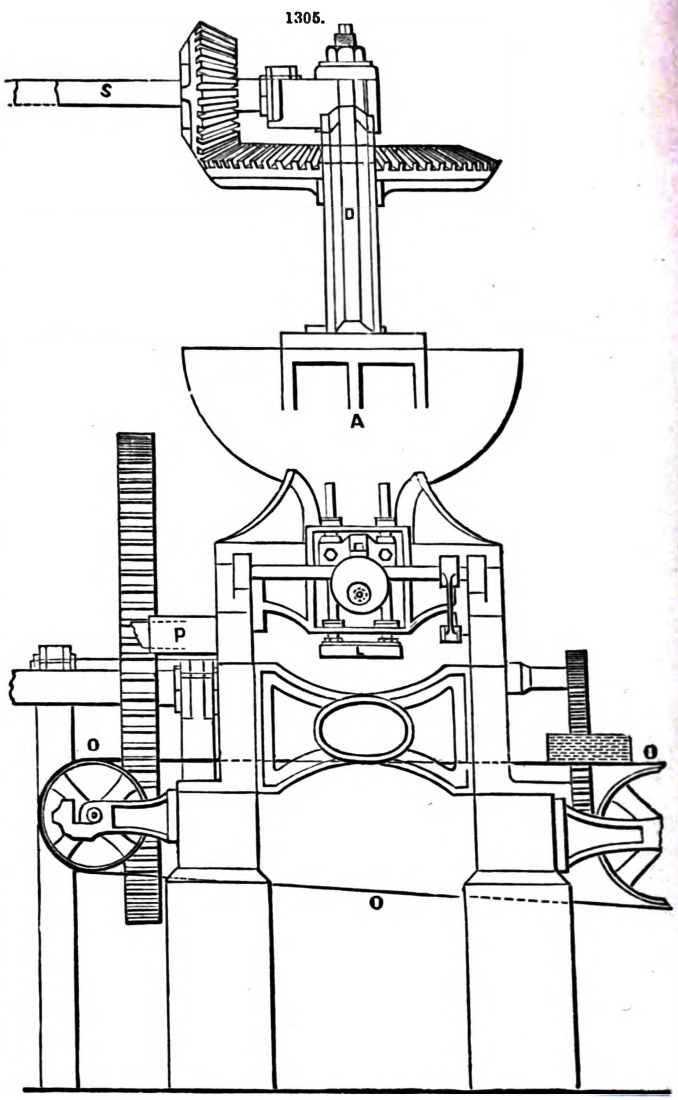


The cast-iron clay cylinder A, Fig. 1308, is expanded at the upper part to form a hopper into which the clay is supplied, and the lower cylindrical portion is about the same in diameter as the length of the brick-mould F at the bottom of the pressing-chamber B. The vertical screw C is placed in the axis of the clay cylinder, and carried by two bearings in the upper frame D: this screw is parallel at the lower part, the blade nearly filling the parallel portion of the clay cylinder, and is tapered conically at the upper part to nearly double the diameter. When the clay is thrown loosely into the hopper, it is divided and directed towards the centre by the curved arm E revolving with the screw-shaft, and drawn down by the tapered portion of the screw into the parallel part of the clay cylinder, in sufficient quantity to keep this part of the cylinder constantly charged, any surplus clay easily escaping laterally into the loose clay in the hopper. The clay is then forced downwards by the parallel portion of the screw into the pressing-chamber B, and into the brick-mould F, which consists of a parallel block. This block is equal in thickness to a brick, and slides between fixed plates above and below; these plates containing the two moulds F and G, Fig. 1310, corresponding in length and breadth to the bricks being made.

The mould-block F, Fig. 1310, is made to slide with a reciprocating motion by means of the revolving cam H, which acts upon two rollers in the frame I connected to the mould-block by a rod sliding through fixed eyes, and the two brick-moulds are thus placed alternately under the opening of the pressing-chamber B to receive a charge of clay; the mould-block remaining stationary in each position during one quarter of a revolution of the cam H. When the brick-mould F is withdrawn from under the press-chamber, the brick is discharged from the mould by the descent of the piston K, which is of the same dimensions as the brick-mould; the piston is pressed down by the lever M worked by the cam N, when the brick-mould stops at the end of its stroke, and is drawn up again before the return motion of the mould begins. A second piston L acts in the same manner upon the second brick-mould G; and the discharged bricks are received upon endless bands O, Figs. 1305 to 1307, by which they are brought successively to the front of the machine, where they are removed to the barrows for conveying them to the kiln to be burned.

The solid block that divides the two brick-moulds F and G is slightly wider than the discharge-opening at the bottom of the pressing-chamber B, having an overlap, so that the making of one brick is terminated before that of the next begins, in order to ensure completeness in the moulding. During the instant when this blank is passing the opening at the bottom of the pressing-

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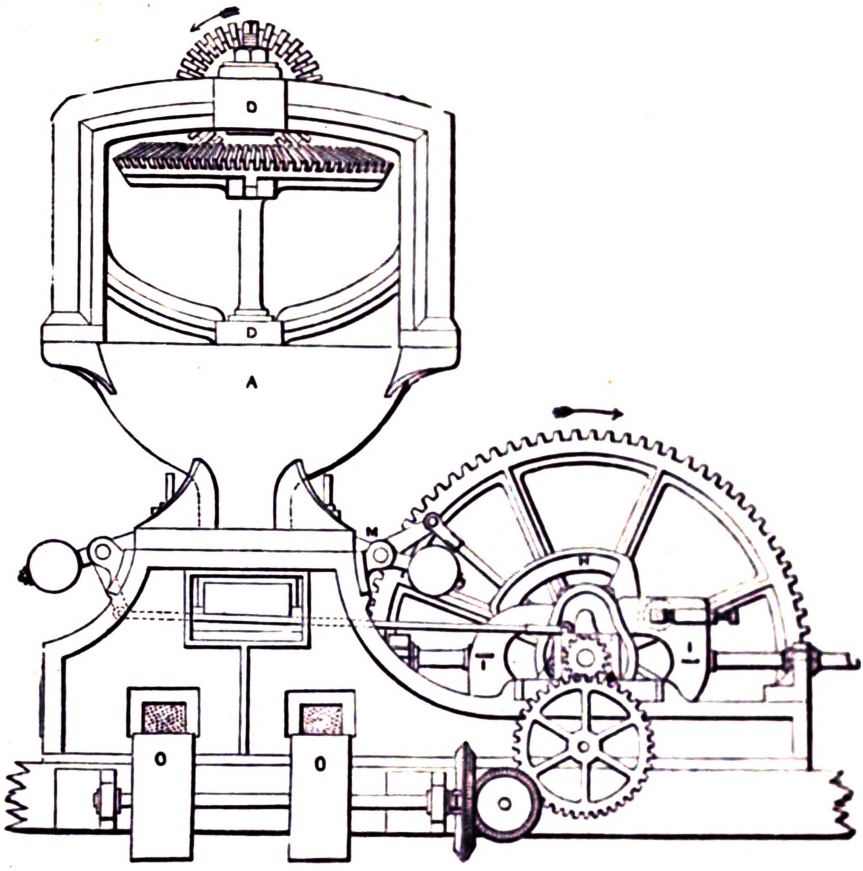


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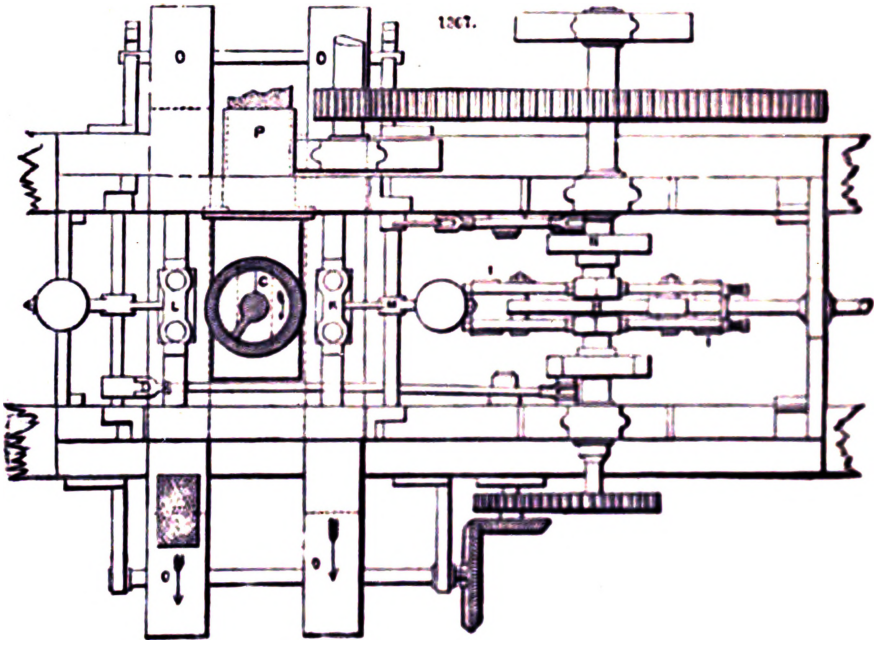

chamber, the discharge of the clay is stopped, and it becomes necessary to provide some means of either relieving the pressure during that period or stopping the motion of the pressing-screw. The latter plan would be impracticable; and in this machine the former mode is established by a very ingenious contrivance, forming in effect a safety-valve, which prevents the pressure in the chamber from increasing when the brick-mould is shut off, and also serves to maintain a uniform pressure during the formation of the brick, so as to ensure each mould being thoroughly and equally filled with clay. This is effected by an escape-pipe P, Fig. 1308, which is similar in form to the brick-mould, but extends horizontally from the side of the pressing-chamber, and is open at the outer extremity. The regular action of the screw forces the clay into this escape-pipe as far as its outer extremity, forming a parallel bar of clay in the pipe: the resistance caused by the friction of this bar in sliding through the pipe is then the measure of the amount of pressure in the machine; and this pressure cannot be exceeded in the machine, for the instant that the brick-mould is full the further supply of clay fed into the pressing-chamber by the continuous motion of the screw escapes laterally by pushing outwards the column of clay in the escape-pipe. The uniform pressure of every brick in the mould up to this fixed limit is ensured by the escape-pipe not beginning to act until that limit of pressure is reached. Its action is similar to that of a safety-valve; and the amount of pressure under which the bricks are made is directly regulated by adjusting the length of the escape-pipe.

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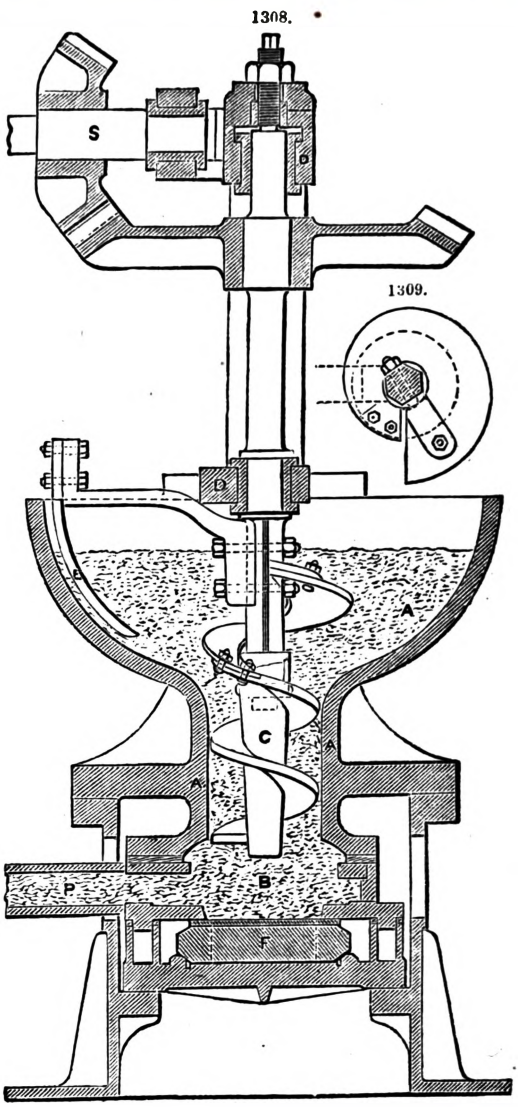


The important result of this arrangement is that it prevents any risk of over-straining the machine; and the action of the screw has a special advantage in filling the brick-mould with a continuous uniform stream of clay, which is being constantly supplied at a uniform moderate pressure, so as to ensure the mould being thoroughly filled with a uniform density of clay throughout, without requiring any sudden excessive pressure that would cause the brick to be more dense on the outside than in the centre. The pressing-chamber is made larger in transverse area than the supplying screw cylinder, in order to increase the uniformity of pressure on the clay in the chamber; and the regularity of action is shown by the working of the escape-pipe, which discharges a continuous bar of solid clay, advancing by intermittent steps of $\frac{1}{4}$ to $\frac{1}{2}$ in. of length each time that the brick-mould is shut off and changed. The projecting piece of clay from the end of the escape-pipe is broken off from time to time and thrown back into the hopper of the machine.

The upper side of the solid block separating the two moulds F and G is faced with steel, as shown in Figs. 1308, 1310, and the upper face of the brick is smoothed by being sheared off by the edge of the opening in the pressing-chamber; the under face of the brick is smoothed by being planed by a steel bar R, Fig. 1310, fixed along the edge of the under-plate, having a groove in it for discharging the shaving of clay taken off the brick.

The screw-shaft is driven by bevel-gear from the shaft S, Fig. 1305, which is driven by a strap from the engine, the speed being adjusted according to the quality of the clay or the wear of the screw. The screw is driven at about thirty revolutions a minute, delivering the bricks at the rate of about 30 a minute when at full speed, or one brick for each revolution of the screw. The machine completes regularly in ordinary work 12,000 bricks a day, or an average of 20 good bricks a minute. The amount of power required for driving the machine and the wear of the screw vary according to the material worked. At the Oldbury Brick Works, where two of the machines have been working regularly for three years, the clay is a calcareous marl, and the power required for each machine is about 12 horse-power; the rate of manufacture is 20 bricks a minute.

The wear of the screw varies considerably, according to the material of which it is made and the quality of the clay worked in the machine. In a machine used by Peto and Betts at Cobham, cast-iron screws have been worn out in a short time with very siliceous material; but in two machines working at Gosport for two years, the screws were renewed only once in that time, although as many as three million bricks were made by the machines. In another machine

working for two years at the Blaenavon Iron Works, the screw and mould-block were made of gun-metal, and were found considerably more durable.

With regard to the burning of the bricks made by these machines, no difficulty has been found from the bricks not having been dried before stacking in the kiln: and a very small proportion of waste is made in the burning. Where the clay contains much alumina and retains more moisture in consequence, it is found advisable to stack the bricks in the kiln in *lifts*, as they are termed, of from fifteen to twenty courses each: as soon as the bottom *lift* has been stacked, small fires are lighted to drive off the steam from the bricks, which might otherwise soften those stacked above; the middle *lift* is then stacked and similarly dried, and then the top *lift*, after which the full fires are lighted. In other cases the whole kiln is stacked at once, and no difficulty has been experienced from the lower bricks not being able to bear the weight of the upper bricks.

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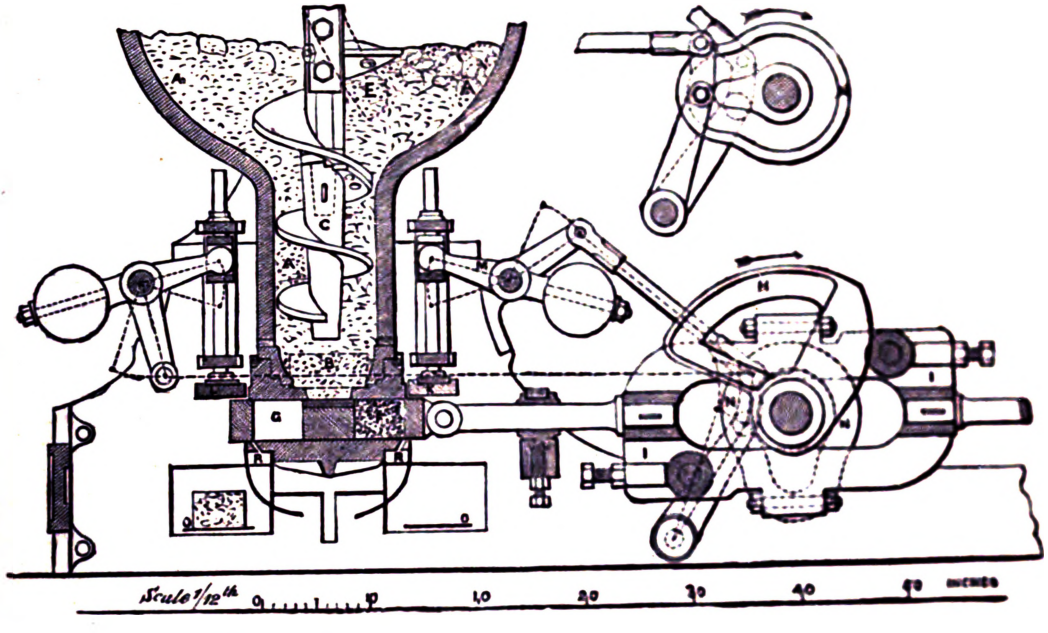
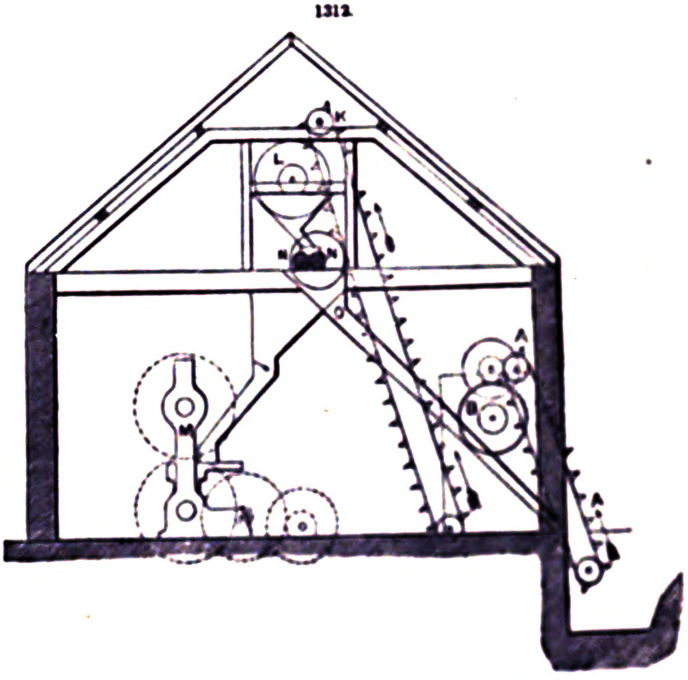



1311.



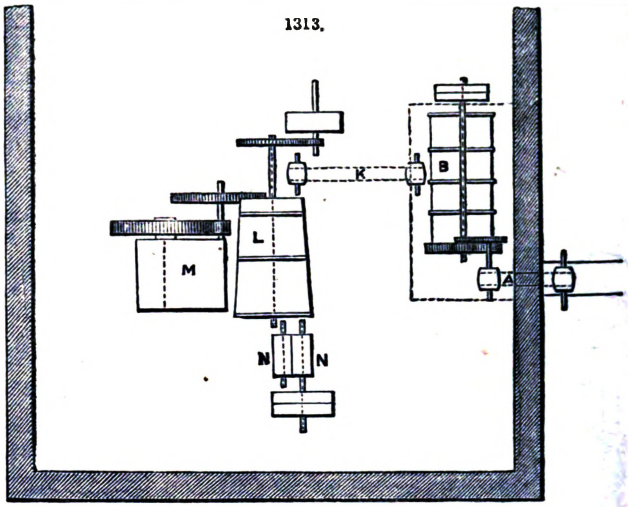
Sections, elevations, and details of Platt and Co.'s dry-clay brick-making machine are shown, Figs. 1312 to 1319. We take a description of this machine from a paper read before the Inst. of Mechanical Engineers, by B. Fothergill. The clay is taken from the bank in tramway trucks to a large shed or covered storehouse, which keeps the machines from injury while being worked in bad weather, when the clay cannot be got sufficiently dry. Under the shed floor is an arrangement of flues that can be heated to dry the clay as it is taken from the bank. From this shed the dry clay is taken by an elevator A, Figs. 1312, 1313, and shot into a hopper at the upper end of a revolving pulverizing machine B, consisting of a screen fixed at a slight inclination from a horizontal position, and so constructed and arranged that the clay is pounded and forced through it by crushers, while stones and other hard substances are ejected at its lower end.

1312.



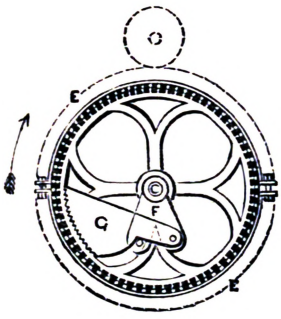
The pulverizer is shown enlarged in Figs. 1314, 1315. The fixed shaft C is set at a slight inclination from the horizontal, and the ends D D of the screen revolve upon it to these ends are bolted the longitudinal bars E E round the circumference, forming the screen. These bars are of a wedge-shaped section, so as to give a wider opening between them on the outer than on the inner side, to allow the pulverized clay a free escape There are also attached to the shaft C within the ends of the screen two bearers F F connected by two longitudinal bolts, which carry a series of cast-iron crushers or pulverizers G G, weighing about ¾ cwt. each one bolt forms a fixed axis at the extremity of the pulverizers; and the other bolt acts as a support for them, in such a manner as to allow a slight space between their extremities and the inner side of the screen-bars E, to prevent actual contact when the machine may be working without clay. The screen is made to revolve at about twenty-five revolutions a minute by a pinion driving the wheel H fixed upon the upper end. The clay is fed in by the hopper I at the upper end, and by the rotary movement of the screen is carried forward and under the pulverizers G, which break up the lumps and press the clay out through the spaces between the bars E; but owing to the manner in which the pulverizers are arranged and supported, they yield and rise when stones or other hard substances are passing under them, preventing any damage to the machine; and in consequence of the inclination at which the screen is set, the stones are gradually traversed through its entire length, and ultimately rejected at the lower end which is left open for the purpose.

1313.

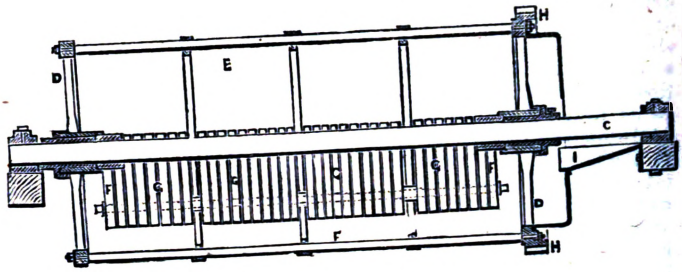



The clay is then conveyed from under the pulverizer by an elevator K, Figs. 1312, 1313, into a revolving conical screen or sifter L, shown enlarged in Figs. 1316, 1317; from which it falls into the hopper of the brick-press M, Figs. 1312, 1313, in a state of fine powder; any particles not passing through the meshes of the sifter L are rejected at its larger end and conveyed by a spout to a pair of small crushing-rollers N, and thence back by the spout O to the foot of the first elevator A, where they are mixed with the crude clay, and go through the same process again.

1314.




1315.

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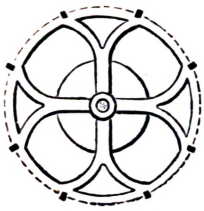
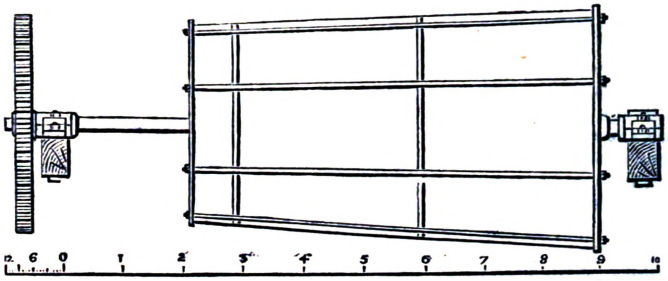


1317.

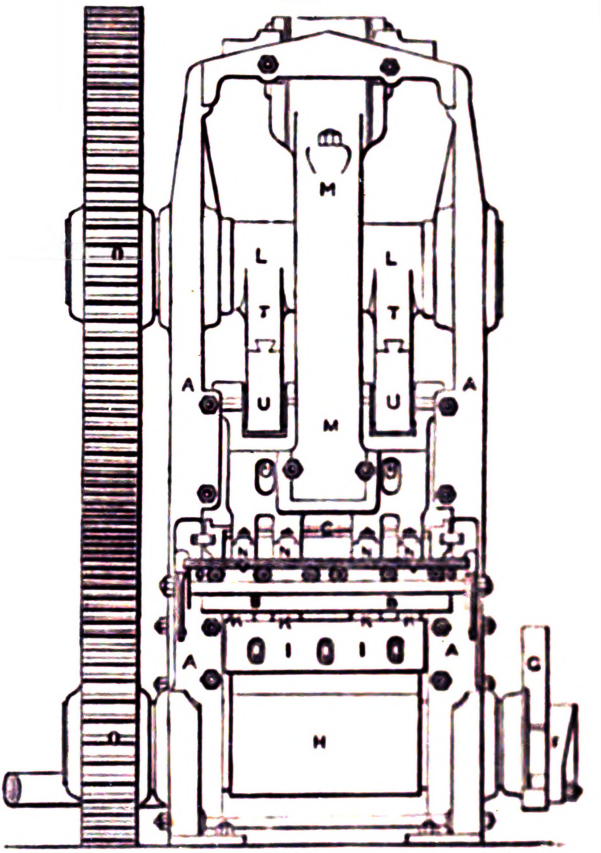



The brick-press is shown enlarged in Figs. 1318, 1319; Fig. 1318 is a front elevation, and Fig. 1319 a transverse section. The side cheeks A A are fixed on the foundation-plate and support the principal parts of the press. B is the frame or bed where the moulds are arranged and in

which the bricks are formed. C is the sliding mould-charger, to take the clay from the hopper D to the brick-moulds; an adjustable striker E is fixed upon the front of the hopper to gauge the charge of clay when being conveyed to the moulds by the forward motion of the lever F, which is actuated by the cam G, shown dotted in Fig. 1319, fixed upon the bottom cam-shaft H. The lower ram I rests upon and is actuated by the cam-shaft H, and is formed with four pistons K upon the upper surface; each of the pistons fits into a separate brick-mould. The top cam-shaft L gives motion to the upper ram M, which is also formed with four pistons N upon the lower surface, exactly corresponding with the four lower pistons K and fitting into the same brick-moulds. The two cam-shafts are driven at the same speed by the spur-wheels O which are driven by the pinion P.

The cams R S lift the upper ram M, and are so arranged as to produce two successive elevations and allow two falls of the ram and pistons in the formation of each series of four bricks made at each revolution of the machine. The first blow of the pistons, after being raised by the first cam R, drives the clay out of the four apertures in the mould-charger C, which have been brought directly over the four brick-moulds by the motion of the lever F and compresses the clay into the moulds, thereby expelling the air from it: a very heavy blow is given by the pistons upon the clay, the total weight of the falling parts being nearly 1 ton. The pistons are then raised by the second cam S to a suitable height to allow the mould-charger C to move back to its former position underneath the hopper D, for the purpose of being filled with another charge of clay. A second blow of the pistons then takes place, thoroughly condensing the clay in the moulds; and the final pressure to finish the bricks is then given on the top side by the pressing cams T acting upon the friction-rollers U which are fixed on the upper ram M: this downward pressure is met by a simultaneous upward movement of the lower pistons K, given by the eccentric form of the bottom cam-shaft H. The shaft H is also formed so as to raise the bricks up to the top surface of the mould-bed B after the pressure is completed, whence they are removed to the table V by the forward movement of the mould-charger C, when delivering the charge of clay for the next set of bricks. An india-rubber buffer-spring X is placed in the upper ram M, to receive the concussion of the fall of the ram upon the cams R S, in case the machine should from any cause run without clay. By this arrangement of applying the pressure both below and above simultaneously, the bricks are kept in continued motion, sliding through the moulds whilst the severe pressure of the cams is taking place; which gives a fine polished surface to the sides of the bricks, and ensures the angles being all filled up completely square.

1318.




The faces of the moulds are formed of wrought-iron plates case-hardened and secured by pins, so that they can be easily removed and replaced, when necessary.

The whole process is thus self-acting, from the crude clay being fed into the pulverizer out of the drying-shed, to the bricks being finished by the press ready for the clamp or kiln, and no waste of material takes place, other than the rejection of the stones by the pulverizer in the first process, and no process of drying the bricks being requisite, they are taken direct from the machine and stacked in the kiln ready for burning, thus avoiding all risk of damage from handling whilst in an unbaked state. The clay may be mixed with breeze or ashes, or chalk for white bricks, or other such substances, the machines working any sort of clay or mixture equally well; the press by its extreme pressure forms a perfect brick in an unburned state, and an uncommon hardness and closeness is obtained.

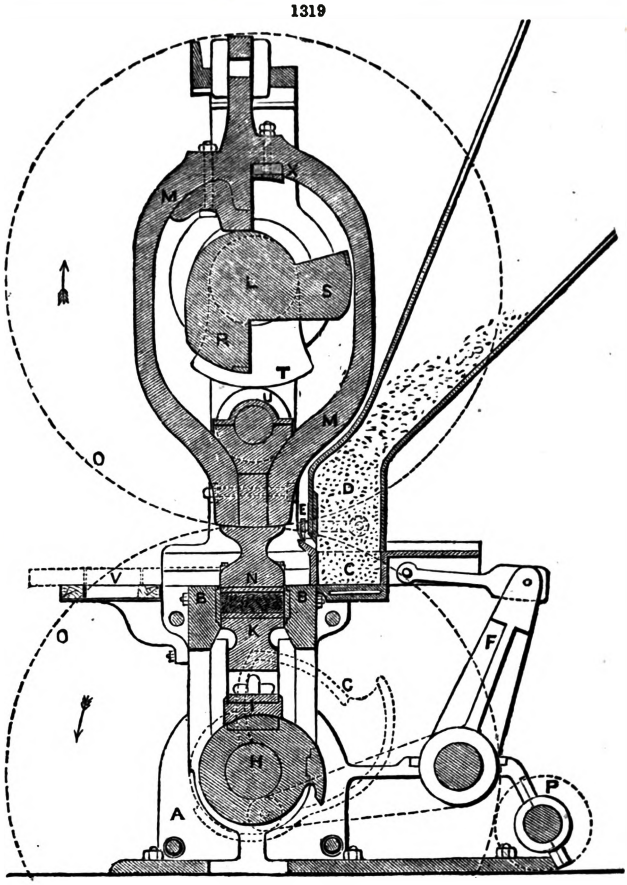
By this process of manufacture, within a quarter of an hour, clay may be taken from the shed in its crude state, and the bricks delivered by the press, taken by a tramway, and landed in the kiln ready to be burned in the usual way. Buildings have been erected with these bricks, and

it is found that with care in setting the bricks the inside surface is as perfect as the outside, and is finished without any occasion for plaster. For bricks so perfectly formed it might be expected that great care would be required in manipulation, and the production must necessarily be slow. The reverse is however the case, and the following is the result of actual working. The machinery prepares the clay and completes the bricks at the rate of 30 bricks a minute, or 1800 an hour, in one day of 10 hours' work 18,000 are produced, giving a total production of 5,400,000 a year of 300 working days. Thus with a very moderate amount of attention paid to burning, which is rendered easy by the great firmness of the bricks, 5,000,000 of perfect bricks may be burned from one machine in a year.

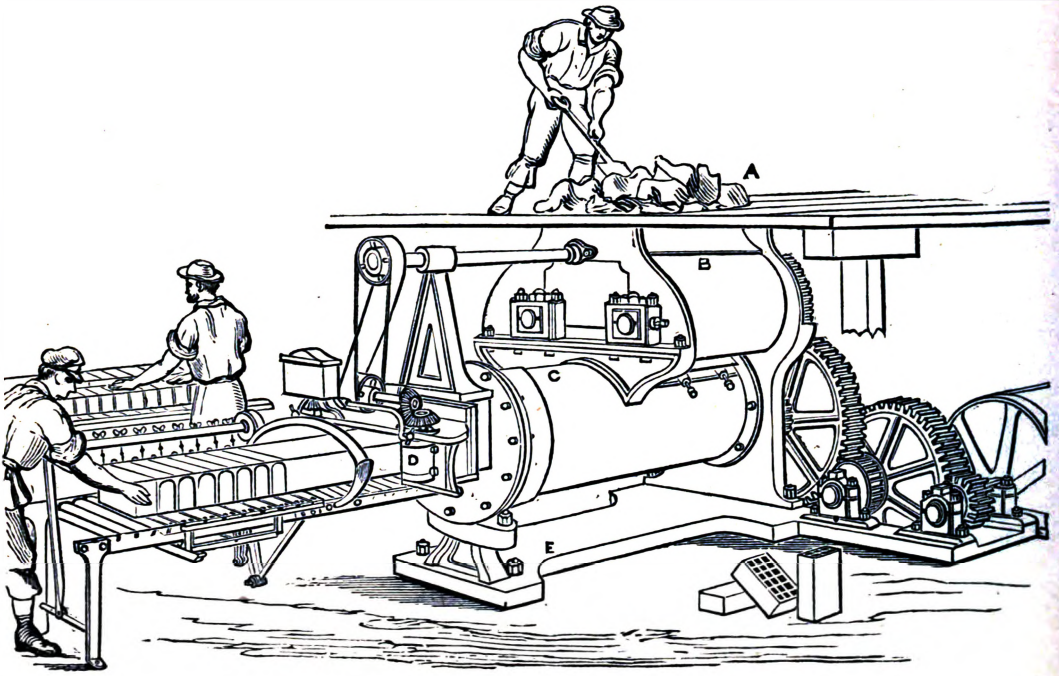
Fig. 1320 is of a brick machine, which requires from 6 to 8 horse-power to produce 12,000 to 18,000 bricks a day, according to the nature of the clay operated upon. This small machine of Clayton and Howlett crushes the clay, pugs the material, and moulds the bricks: it is a very complete machine.

The rough clay A is taken from the heap in barrows and wheeled up an incline, or it is drawn up the incline by suitable gearing by the power of the machine, and then shovelled into the feeding-hopper B, in which revolves a shaft which has several small knives fixed upon it; the duty of these knives is to cut up the large lumps of clay, and at the same

1319




1320.

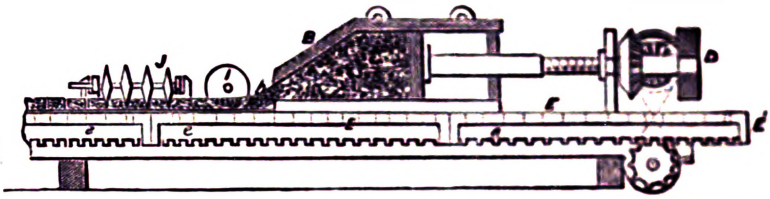


time to press it down upon the rollers incased in B, and further, to prevent the receiving-hopper from becoming choked.

The crushing-rollers next grip the clay, and crush all hard lumps and large stones, and force the thus partially-prepared material to the pug-cylinder C, in which revolves a strong shaft fitted with a number of knives, set in such a manner so as to form sections of a screw, which by their rotary action thoroughly *puq* or mix the *clay*, and at the same time force the homogeneous mass towards the end D of the cylinder, where it passes through the die or moulding orifice on to the cutting-off tables.

David Murtha's *brick machine*, Fig. 1321, has a series of rotating circular disks I, arranged so

1321.



as to operate upon the clay, which, after being forced from the narrow opening b of the clay receptacle, is cut into strips of the proper width of the length of the brick. In front of the disks I is a transverse series of similar disks J, for the purpose of cutting the strips of clay into the proper widths. The feeding-table E' E *e* is made in sections, so as to admit of being passed successively through the machine.

1323.

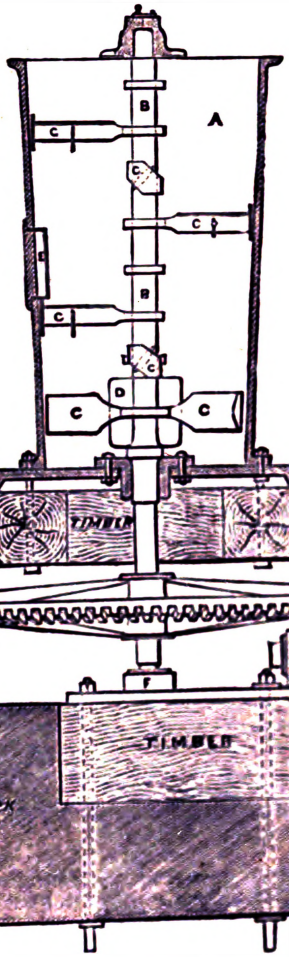
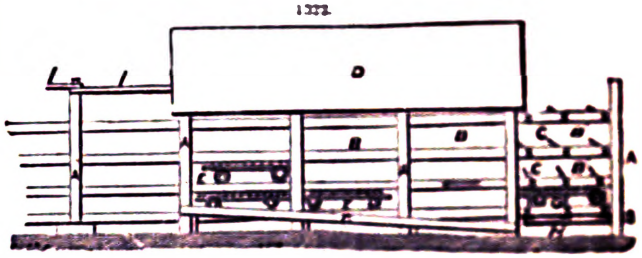
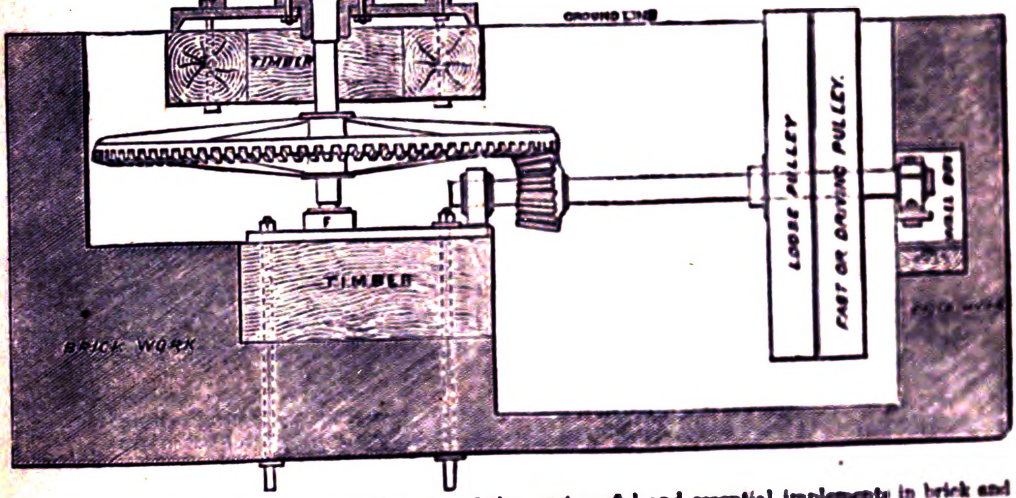


Fig. 1322 shows S. M. Parish's apparatus for *drying bricks*. It has a combination of adjustable supports G, to prevent the weight of the bricks from sagging the board, which rests on a carriage. A rod which connects

1322.



the slats is pivoted on journals, and used in connection with a carriage E and movable rails. B B are covered tracks; G H adjustable loading-stays; B' B' movable extension-rails; A A posts; I stringers; C the return tracks; and D the roof of the shed.




*Pugging.*—The pug-mill is one of the most useful and essential implements in brick and tile manufacture. The object of pugging the clay is to bring it into a complete homogeneous state of consistency. In the clay as dug, with rare exceptions, the strata are various. In some portions the unctuous, in others the sandy, siliceous, or other qualities prevail. In order to work brick-

clay properly and effectively, it is indispensably necessary to incorporate its various component parts, and to make it of one *uniform character*. The pug-mill is therefore the most valuable and important precursor of the subsequent processes of brick as well as of *tile manufacture*, inasmuch as the equal consistency and integrity of the raw material can alone ensure the uniform strength and good quality of the completed brick or *tile*. H. Clayton and Co.'s improved Archimedian knife pug-mill, Fig. 1323, produces these desirable results.

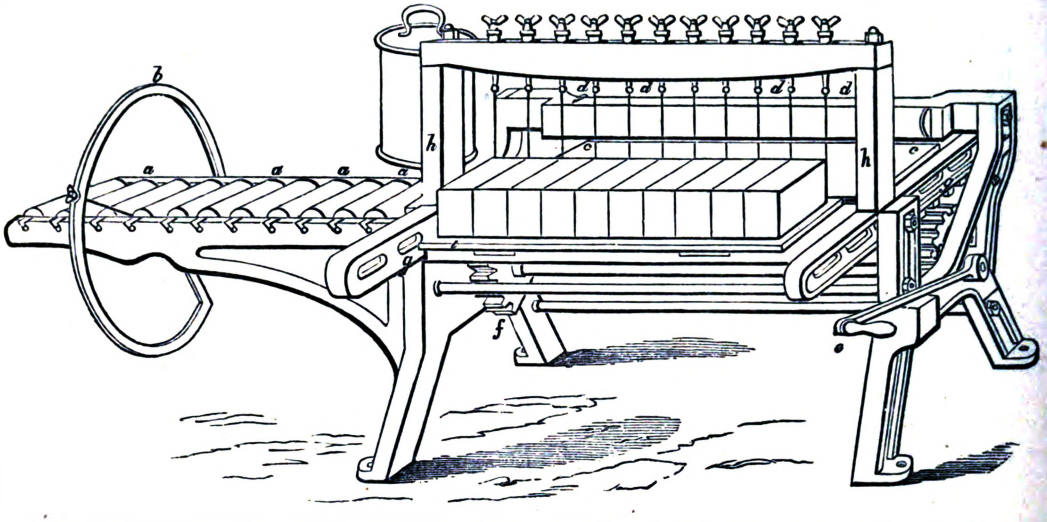
In Fig. 1323, A is a cast-iron cylinder into which the clay required to be pugged is thrown. Upon the central shaft B are fixed wrought-iron steel-tipped knives C, C, C, C (so placed as to form a section of a screw), which cut up and mix the clay, and at the same time force it downwards to the outlet D at the bottom of the cylinder, which can be adjusted with a sluice-door and lever for letting the clay out at certain times.

There is a door E, fastened with a strong wrought-iron bar, in the middle of the mill, for convenience, when it is necessary to inspect and clean the knives from roots and other foreign materials that may adhere to them.

The bottom end of the pug-shaft B works in a steeled bushed step F.

*Clayton, Son, and Howlett's Brick-cutting and Self-delivery Table*, Fig. 1324.—When a stream of clay of sufficient length to cut the desired number of bricks has been expressed from the die or

1324.




moulding orifice of the machine on to the receiving-rollers *a*, *a*, *a*, the single cutting-wire *b* is caused to pass through the stream of clay to sever or divide it. The desired length of moulded clay being now cut off from the mass, it is drawn forward by hand over the receiving-rollers on to the cutting or plate table *c*, in front of the cutting-wires *d*, *d*, *d*, so that the expression of the main stream of clay from the moulding machine may continue without interruption, whilst the severed portion intended to be cut up remains stationary.

This portion of the moulded clay is now ready to be cut up into bricks, which is done by causing the wires to pass through it by means of operating the handle *e*, which simultaneously transmits motion to the pinions *f f*, the racks *g g*, and the whole rack-frame *h h*, carrying with them the series of wires *d*, *d*, *d*, and also the plate-table *c* and platen or board *i*, causing the plate-table *c* to pass from under the clay through which the wires are passing, and to be replaced by the portable platen or board *i*. The handle *e* is now to be moved in the opposite direction, by which the whole movable parts described are returned to their original position, taking with them the clay now in form of cut bricks on the platen or board *i*. this platen or board *i* is then removed with the bricks upon it. Another board being substituted, the machine is now in position to repeat the operation.

One of the great advantages of this table over those previously in use consists in the perfect ease with which a large number of bricks can be cut and safely removed from the machine in a given time. This is effected, not by increasing the quantity of material coming from the moulding machine, but by the greatly-increased facility for the required operations, and by lessening the number of the waste pieces of moulded clay. It also wholly supersedes the risk and labour in the removal of the bricks from the machine. In other machines of the kind the cut bricks have to be removed from the table separately to place them on the barrow, rendering this portion of the operation subject to loss or damage of the bricks by negligence of the workmen.

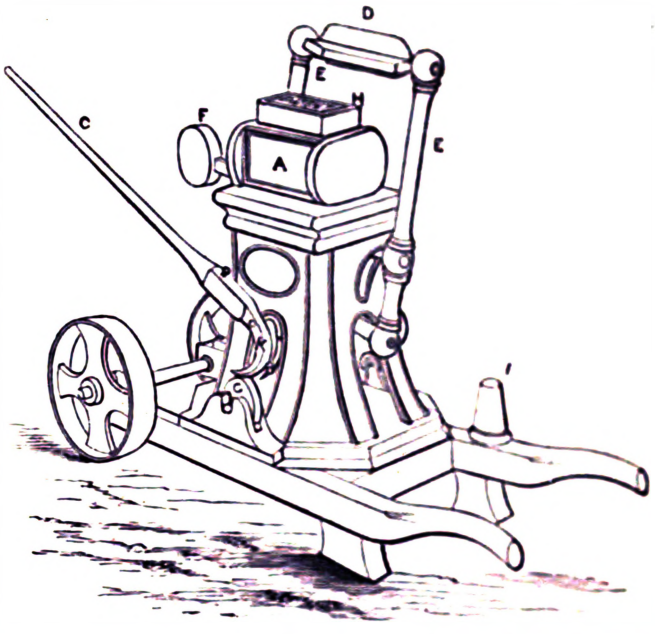
In this table these practical objections are avoided, as by its arrangement a positive number of (ten or twelve) bricks is cut and delivered, by one simultaneous operation, each time of cutting on to a receiving palette or board ready to be placed upon the brick barrow without the cut bricks having been handled in any way.

This table also possesses the advantage of being available for any variation of length of brick and for any required angle of cut, or for arch bricks, simply by removing the two strain-bars between which the wires are stretched, and by replacing them with other bars of the desired gauge, thus superseding he necessity of the outlay hitherto necessary for a series of separate cutting-tables. The action of this table is such, that whilst the wires are passing through the

clay, it is held true and firmly against a smooth metallic resistance-plate; thus the finish of the cut is clean and the ends of the bricks are square, and not left ragged or torn.

*Hand-power Brick-pressing Machine*, Fig. 1325.—This little machine of Messrs Clayton and Howleft is the most perfect of the kind that has fallen under our notice. A is the mould box or chamber, in which a piston is moved up and down by means of partial revolution of a cam on the cam-shaft B, actuated by the hand-lever C; this cam-shaft is connected with the top-cover D by the side arms E, and moves up and down with it, but when pressing is free to reciprocate on its own centre without moving the cover or side arms. F is a weight attached to the cam-shaft, and vibrates with the hand-lever C, which being sharply thrown over, adds considerably to the pressure by its own momentum. G is a friction-roller on which the curved end of the hand-lever works when delivering the bricks, and by pulling the hand-lever over in the position shown in the engraving, the whole of the cam-shaft, with the side arms and cover, are bodily raised, and the piston is brought up flush with the top edge of the mould-box. The rough brick H to be pressed is now placed upon the piston, and the lever is brought over to the right stop I. The curved end K travels upon the friction-rollers, and the whole cam-shaft, side arms, top-cover, and the piston with the brick, are lowered until the lever arrives at a perpendicular position, by which time the cover has been brought into its proper position on the top of the box by the guides; the cam-shaft is now entirely supported by the side arms and cover, and simply reciprocates upon its own centre, which motion causes the cam to raise the piston and compresses the brick. The lever is now thrown sharply back to the opposite side, which action causes the curved end of the lever to ride upon the roller, and bodily raises the cam-shaft, the top-cover, and the piston, and delivers the brick ready to be taken away.

1325.




One of the great features in this press is the patent self-lubricating piston, whereby a great saving of time is effected, and the great desideratum of preventing the adhesion of the brick to the mould has been obtained.

*The process of washing* is resorted to for the effectual separation of limestones and other substances from earths into which they, injuriously to the manufacture of clay wares, intrude—or for those classes of bricks, such as London stocks, with which for a special object chalk is largely mingled with the clay. For such object Roller and Harrow Wash-Mills are much used, and they are applicable separately as chalk-mills. These mills are also used in cases where a special manufacture renders the washing of the clay, or of the whole of the raw material, necessary.

1326.

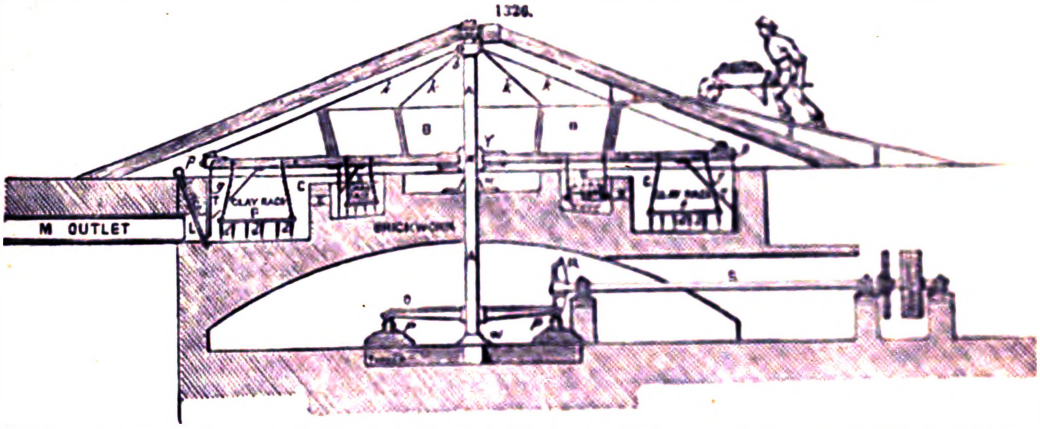


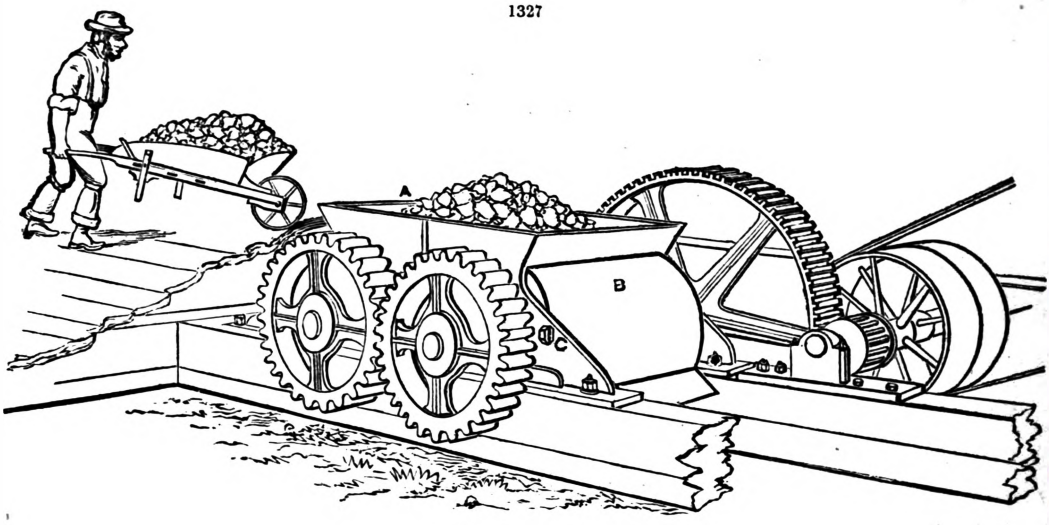

Fig. 1326 represents a cross-section of one of Clayton and Co.'s Clay and Chalk Washing-Mills: there are two races D, C, the minor one D for chalk, and the outer C for clay. A is a central iron shaft.

supported at the top, bottom, and centre by the steps V, W, W′; to this shaft is fixed a 6-way beam-socket Y, into which are fitted and secured six harrow beams, two of which are shown at E, E, Fig. 1326, radiating from Y. Upon these beams E, E, are fastened harrows F, F, by means of chain slings *g*, *g*, which when the mill is at work permit of the harrows making a zig-zag motion. The chalk race D is furnished with three spike-rollers, one of which is shown, in Fig. 1326, at H. Besides the harrows we have mentioned, there are two others attached to their respective beams E in the chalk race D.

The ends of the harrow beams E are supported by tie-bolts K, K, K, K, which are secured to a lug-ring *b* at the top of the centre shaft A. The tie-bolts are carried through the lugs on the beam-caps *p*, and can be tightened up when required by the nuts at *p*. Scrapers T T are fixed at the ends of the beams to keep the sides of the races clean. Motion is given to the central shaft through a bevel-pinion R on the lay shaft S and bevel-wheel O keyed on the central shaft A. This bevel-wheel O works on antifriction rollers P, P, fitted beneath it. Chalk is thrown into the hopper B (secured on to and revolving with the beams E), and passes into the chalk race D, where water is introduced. The material becomes quickly liquefied, and passes through the apertures Z Z into the clay race C, wherein is thrown the clay, &c., required to be washed, which is here worked by the harrows, reduced to a thick liquid state, and amalgamated with the chalk water. The limestones precipitate, and the liquid mixture is let off through the sluice L and outlet M to the "back," or reservoir, where it remains until of suitable consistency for being moulded.

*Crushing.*—In Fig. 1327 A is the receiving-hopper of Clayton's Clay-crushing Mill, into which

1327




the earth requiring to be crushed is thrown. B, B′, are cast-iron chilled rollers, bored and keyed upon wrought-iron shafts, which work in gun-metal bearings. The rollers B, B′, may be set nearer or closer, as desired, by means of the set screws C, C′, so that the stones and lumps of hard clay may be crushed as well as the finer material. The machine is fixed upon a strong timber framing; round the receiving-hopper A a platform is usually erected for the convenience of wheeling the clay to the mill.

*Vertical Pugging and Moulding Machine.*—The machine of which Fig. 1328 is a side elevation and Fig. 1329 a plan, is sometimes termed a *two-process* brick-making machine. This machine of Clayton and Co. is very substantial and complete; C is a cast-iron vertical cylinder fitted at top with a sheet-iron hood or guard H (for convenience in feeding), mounted and bolted firmly upon a strong cast-iron framework F F and foundation-plate $F^1$. S S are two side frames, also bolted to framework F F and to foundation-plate $F^1$, whose duty is to carry the expressing or mould-feeding rollers R R. The vertical cylinder C is furnished with a strong, square, wrought-iron pug-shaft $S^1$, turned at ends, and into which are fitted and secured single wrought pugging-knives or blades B B B B, so disposed as to form sections of a screw, and at bottom of the cylinder one double delving-blade or sweeper D, forged in form of ȝ. Motion is given to this pug-shaft $S^1$ by means of bevel-wheel W, keyed upon the vertical shaft, and pinion W fitted upon the pulley-shaft A underneath the cylinder-plate F. The vertical shaft $S^1$ runs in a step T bolted to the foundation-plate $F^1$, and is supported by a collar $B^1$ in the cylinder-plate F, and also by a bridge-bar $B^2$ fitted at the top of cylinder, thus rendering the whole substantially rigid. A sluice-valve V is adjusted at the bottom and outside of the cylinder C, opposite to the expressing-rollers R R, fitted with regulating-screw and wheel $S^2$. Two wrought-iron carriage-bars C′ C′ are bolted to cylinder-frame F F and roller-frame S S, into which are fixed small rollers R′ R′, making a framework bridge for the passage of the pugged earth from the sluice-valve V to the rollers R R.

P P are segmental packing-pieces of wrought iron inserted in suitable recesses inside the roller side frames S S fitted with set screws, so that they may be pressed against the ends of the rollers R R, to prevent the passage of the clay between the rollers and the side frames, and compensate for the wear of these parts. The rollers R R receive motion by suitable strong spur-wheel gearing from the horizontal pulley-shaft A and pinion P′ through the intermediate shaft

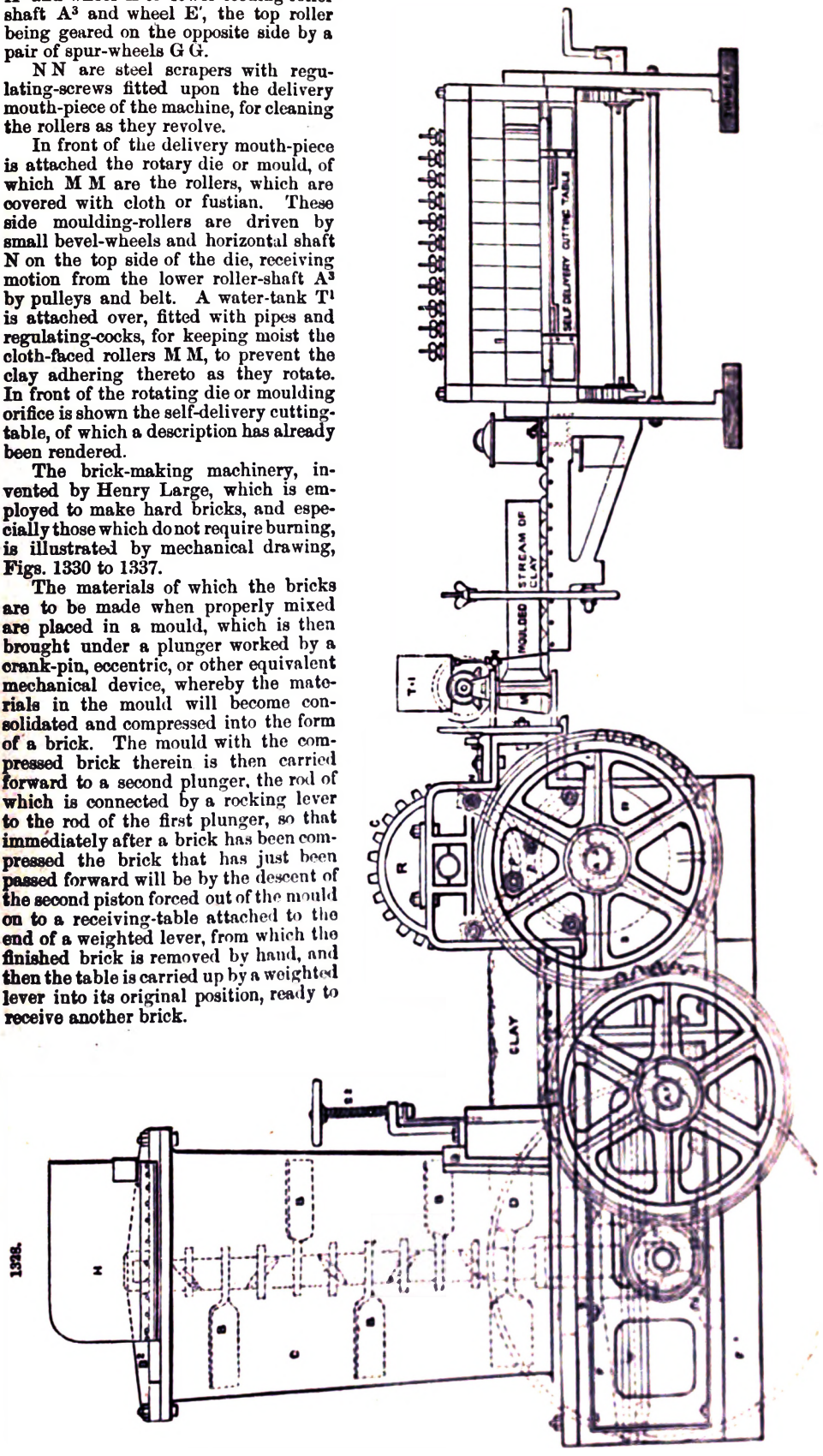
$A^2$ and wheel E to lower feeding-roller shaft $A^3$ and wheel E', the top roller being geared on the opposite side by a pair of spur-wheels G G.

N N are steel scrapers with regulating-screws fitted upon the delivery mouth-piece of the machine, for cleaning the rollers as they revolve.

In front of the delivery mouth-piece is attached the rotary die or mould, of which M M are the rollers, which are covered with cloth or fustian. These side moulding-rollers are driven by small bevel-wheels and horizontal shaft N on the top side of the die, receiving motion from the lower roller-shaft $A^3$ by pulleys and belt. A water-tank $T^1$ is attached over, fitted with pipes and regulating-cocks, for keeping moist the cloth-faced rollers M M, to prevent the clay adhering thereto as they rotate. In front of the rotating die or moulding orifice is shown the self-delivery cutting-table, of which a description has already been rendered.

The brick-making machinery, invented by Henry Large, which is employed to make hard bricks, and especially those which do not require burning, is illustrated by mechanical drawing, Figs. 1330 to 1337.

The materials of which the bricks are to be made when properly mixed are placed in a mould, which is then brought under a plunger worked by a crank-pin, eccentric, or other equivalent mechanical device, whereby the materials in the mould will become consolidated and compressed into the form of a brick. The mould with the compressed brick therein is then carried forward to a second plunger, the rod of which is connected by a rocking lever to the rod of the first plunger, so that immediately after a brick has been compressed the brick that has just been passed forward will be by the descent of the second piston forced out of the mould on to a receiving-table attached to the end of a weighted lever, from which the finished brick is removed by hand, and then the table is carried up by a weighted lever into its original position, ready to receive another brick.



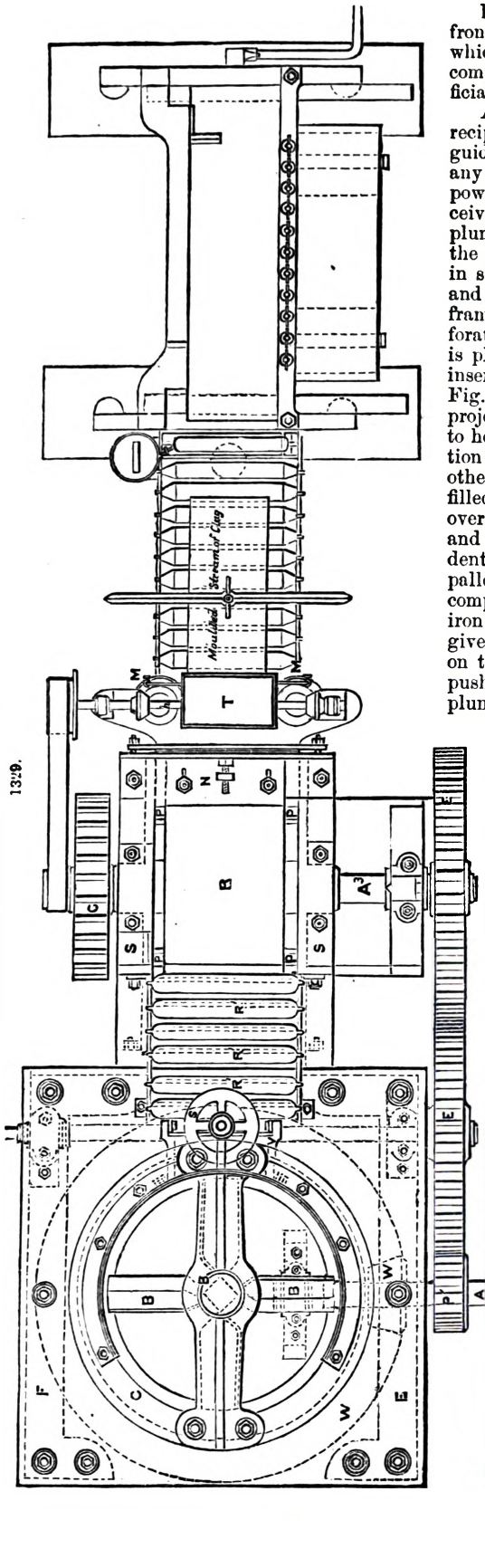
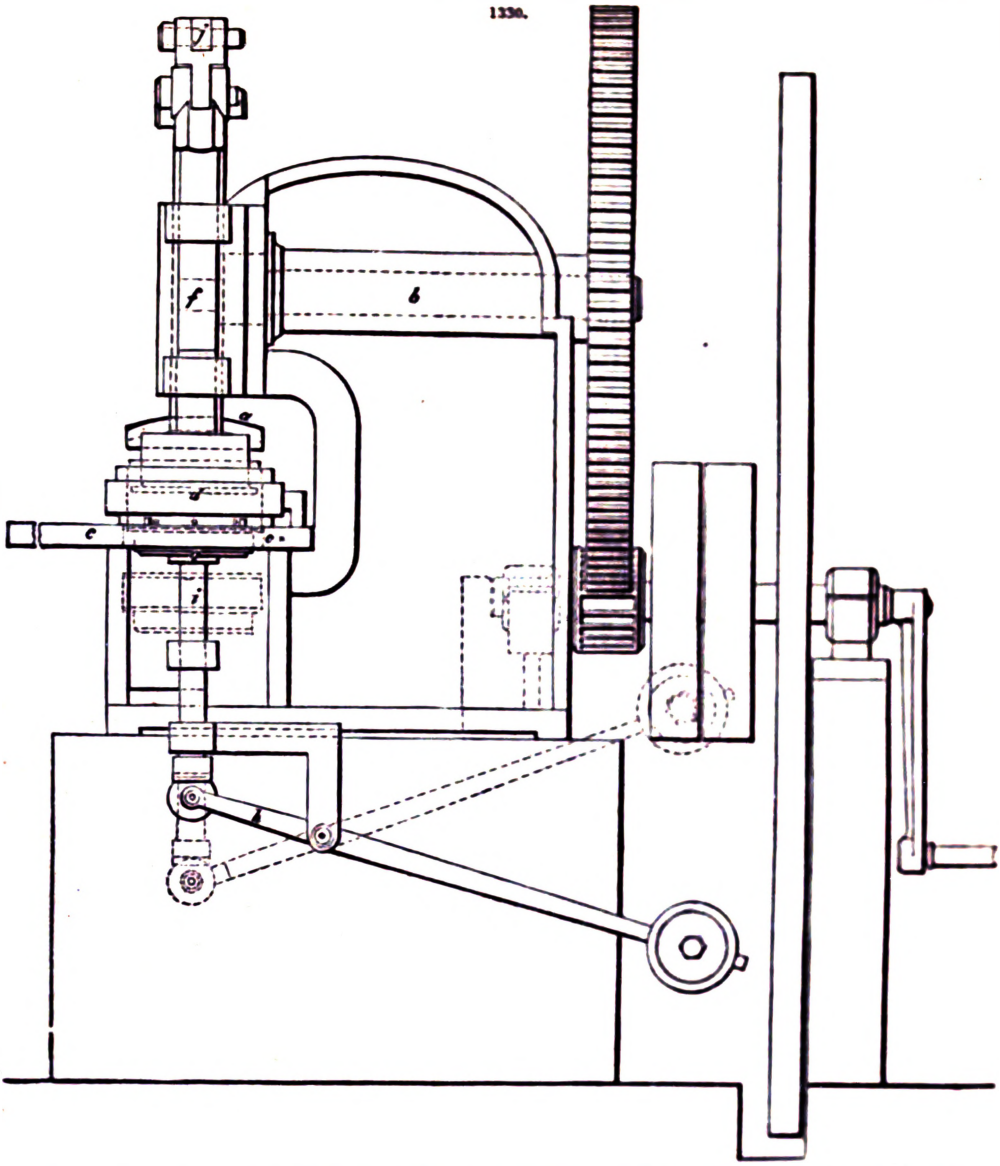



Fig. 1330 is a side elevation, and Fig. 1331 a front elevation, of one of Large's brick machines, which may also be employed for moulding or compressing peat or small coal into bricks of artificial fuel.

A plunger *a* is employed, to which a vertical reciprocating motion up and down in suitable guides is communicated by an axis *b* driven in any convenient manner by steam, horse, or manual power, and carrying a crank-pin *b**, which is received into a horizontal slot in the stem of the plunger *a*; beneath which is a table *c* to support the moulds *d*, which moulds are shown detached in side view at Fig. 1332, end view at Fig. 1333, and plan view at Fig. 1334, and are rectangular frames open at the top and bottom, and perforated on both sides and both ends. The mould is placed on the table, and into it there is first inserted an iron pallet or bed, shown detached in Fig. 1335; this bed is perforated, and having a projection upon it to form an indent in the brick to hold the mortar. The brick-making composition or material, or peat, turf, or small coals, or other substance to be operated upon, is then filled into the mould in suitable quantity, and over it is inserted another pallet also perforated, and having a projection upon it to form an indent on the other side of the brick. Or plain iron pallets can be used, which would be the case for compressing peat, turf, or small coal. Then the iron plate *e*, shown detached Fig. 1336, which gives the required thickness to the brick, is put on the top pallet. The mould thus charged is pushed along the table *b* and brought under the plunger *a*, and the plunger coming down on the top of the iron plate *e* powerfully compresses the contents of the mould and forms the material into a brick, or any other form desired. The plunger immediately rises, and the first mould is pushed on, and the plate *e* is taken out, whilst another similarly charged mould is brought into position to receive the pressure at the next descent of the plunger. Each mould after passing the moulding plunger is pushed outwards until it comes over an opening in the table, as at *c**, slightly larger than the inside of the mould. While the mould is resting on the table *c* it receives a second plunger at the lower end of the rod *f*, whereby the brick or substance in the mould is forced out of it on to a palm *g*, which is held up against it by a counterbalance weighted lever *h* acting against the lower end of the vertical rod *i*. The second plunger has a reciprocating vertical motion given to it by means of a link, whereby it is connected to a rocking lever *j*, the opposite end of which is similarly connected to the rod of the first plunger *a*. The finished brick or substance in the mould, together with the bottom and top pallets, remain on the palm *h*, their weight being sufficient to keep

1336.



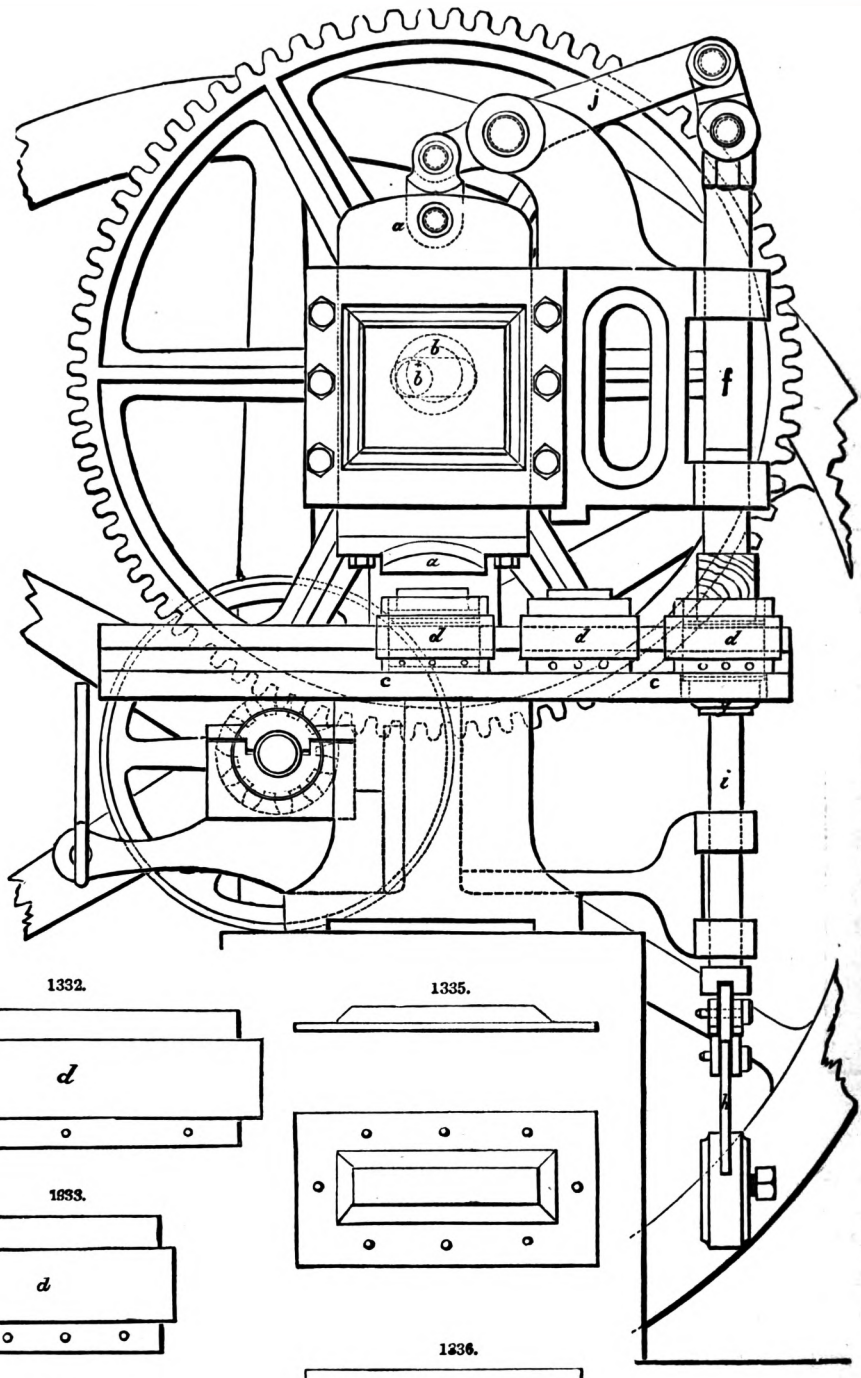

the palm down. As each brick or substance is removed the palm A again ascends to receive the next brick, and the empty mould is conveyed away to be refilled. On the same principle that one brick or substance is compressed in the manner described, two or more can be made at one stroke by using several plungers, and also can be driven out of the moulds by a second set of plungers.

Figs. 1337, 1338, show another arrangement of Large's machine. The bricks made by this machine are not burnt, but merely mixed, in proportions of sand and cement, and pressed into moulds of the required size; they are then laid on the ground or on shelves for forty-eight hours, to harden, after which they are stacked in the open air, exposed to the weather, and in fourteen days are ready for use. These bricks increase in hardness for twelve months, after which they resist the action of frost, and do not absorb moisture. The first patent for making concrete bricks was that of Hustwayte and Gibson, in 1853. In 1856 L. D. Owen introduced a plan of making concrete bricks which has been worked most successfully in South Wales. In the town of Newport many of the houses are built of these bricks, and one firm in the town manufactures 50,000 a week.

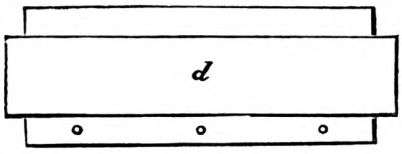
Thomas Don, the eminent machinist, gives the following as the result of some experiments by hydraulic pressure:—

| | Showed 1st flaw | Crushed at |
|---|---|---|
| | Tons. | Tons. |
| 1. A stock brick, as ordinarily made, cracked at .. .. .. .. .. | 1½ .. .. | 8 |
| 2. A compressed concrete brick, composed of 1 part cement and 6 parts coarse sand, 14 days made .. .. .. .. .. | 10 .. .. | 18 4/8 |
| 3. Hand-made concrete brick, 1 part cement, 6 parts burnt *ballast* and boggin mixed, made 7 weeks .. .. .. .. .. | 7 .. .. | 17 4/8 |
| 4. A malm paviour, very well made and burnt .. .. .. .. .. | 5 .. .. | 31½ |

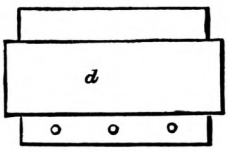
1331.



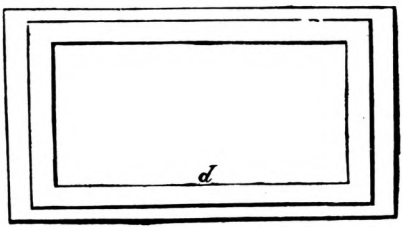

1332.




1333.



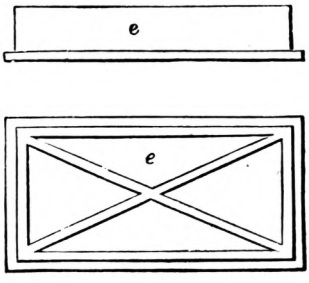

1334.



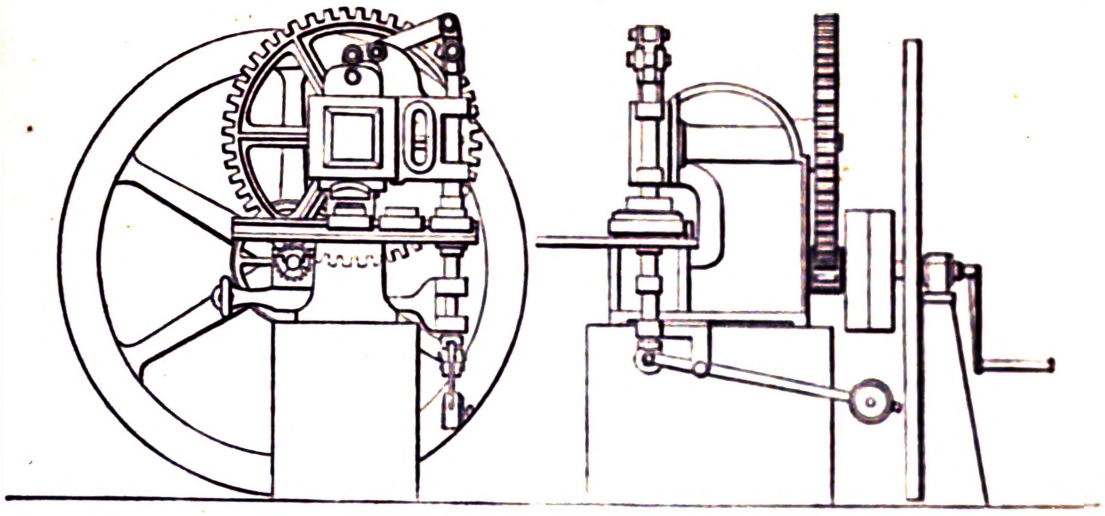

1335.



1336.



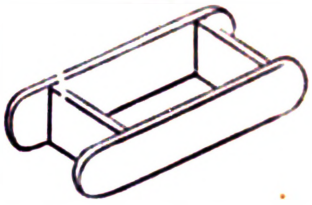
1337. 1338



*Moulding of Bricks.*—The *mould*, Fig. 1339, for forming the bricks is $\frac{1}{12}$ to $\frac{1}{10}$ larger than the size of the brick to be made, as the clay shrinks in burning.

Brick-moulds may be made of any hard wood, which should be thoroughly seasoned, and the edges, which wear very fast, should be protected by a thin strip of iron. Moulds should be frequently gauged, especially when the brick-makers find their own moulds, or the bricks made will vary very much in thickness. Brick-moulds are now made lined with brass, which shows the importance attached to the correct moulding of bricks.

1339.



Two methods of moulding are employed, namely, *slop* and *sand* moulding. In the former the mould is dipped in water every time it is used: in the latter it is sprinkled with fine sand, or with ashes from an old brick kiln. In either case the brick-earth should not be used too wet; and it should be pressed carefully and thoroughly, so as to fill the moulds. The superfluous earth is then removed by a *strike*, which is a straight-edge of wood or metal passed along the top of the mould, and pressed well down on its edges. Steel strikes are best, as wooden ones are cut by the edge of the brick-mould, and then scrape away too much of the surface of the brick, thereby rendering its thickness irregular.

Bricks made by hand are moulded on boards or benches; in India, mostly on the ground, which should be made as smooth and even as possible. At Roorkee, smooth plastered terraces have been used, the surface sprinkled with fine sand or ashes. The bricks are moulded side by side till the terrace is covered; they are then left on it till dry enough to be turned on edge without loss of shape; then, after another short interval, stacked, or, as it is called, laid in a *hack*.

*Drying.*—The bricks should be left in stack until thoroughly dry, as, if put into the kilns damp, the strong heat of the kiln will dry them too suddenly, and probably split or partially disintegrate them.

In drying bricks, they must be protected from the sun, wind, rain, and frost; and each brick must be dried uniformly from the surface to the centre.

Slop-moulded bricks are usually dried on flats or on drying-floors, where they remain from one day to five or six, according to the state of the weather. When spread out on the floor they are sprinkled with sand, which absorbs the superfluous moisture, and renders them less liable to crack in the sun. After remaining on the floors until sufficiently hard to handle without injury, they are built up into hacks under cover, where they remain from one to three weeks, until ready for the kiln. In wet weather they are spread out on the floor of the drying-shed, and great care must then be taken to avoid draughts, which would cause the bricks to dry faster on one side than the other. To prevent this, boards set edgeways are placed all round the shed to check the currents of air.

The ground required for drying bricks in this manner is comparatively small, as they remain on the floors but a short time, and occupy little space when hacked in the hovels. The produce of a single moulding-stool by the slop-moulding process seldom exceeds 10,000 a week, and the area occupied by each stool is, therefore, small in proportion. Half an acre for each kiln may be considered ample allowance for the working floor and hovel.

In places where brick-making is conducted on a large scale, drying-sheds are dispensed with, and the hacks are usually built in the open air, and protected from wet, frost, and excessive heat, by straw, reeds, matting, canvas screens, or tarpaulins.

Bricks intended to be clamp burnt are not dried on flats, but are hacked at once on leaving the moulding-stool, and remain in the hacks much longer than bricks intended to be kilned. This is rendered necessary by the difference between clamping and kilning. In the latter mode of burning,

the heat can be regulated to great nicety; and if the green bricks, when first placed in the kiln, be not thoroughly dried, a gentle heat is applied until this is effected. In clamping, however, the full heat is attained almost immediately, and, therefore, the bricks must be thoroughly dried, or they would fly to pieces.

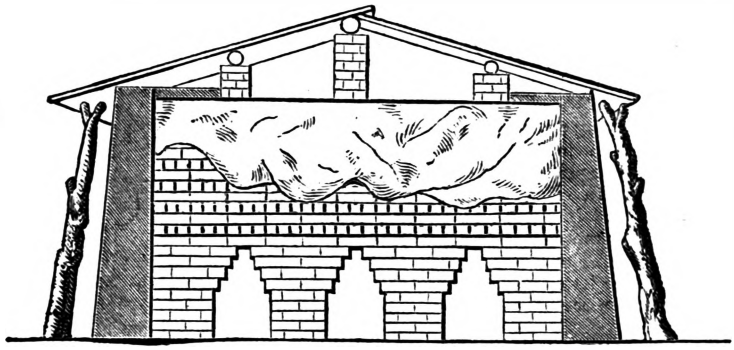
We append some useful directions and practical remarks on the burning of bricks, taken from 'The Roorkee Treatise on Civil Engineering,' edited by J. G. Medley.

The *burning of bricks* is an operation of great nicety, because if not burnt enough they will be soft and worthless, and if overdone, they vitrify, lose their shape, and often run together so as to be inseparable and useless. Various methods have been adopted for producing the due degree of firing. In general, bricks are burnt, both in America and England, in a brick kiln; but in London, the burning constantly takes place in the open air, the bricks being made up into immense quadrangular piles or clumps, consisting of from 200,000 to 500,000 bricks in each. In India both kilns and clamps are used.

*English Kiln.*—A *brick kiln*, as usually constructed, is formed of bricks built in a square form like a house, with very thick side walls, and a wide doorway at each end, for taking in and carrying out the bricks; but these doors are built up with soft bricks laid in clay, while the kiln is burning, and a temporary roofing of any light material is generally placed over the kiln to protect the raw bricks from rain while setting, and so made that it may be removed after the kiln is fired. The English kilns are generally 13 ft. long, 10 ft. wide, and 12 ft. high, which size contains and burns 20,000 bricks at once. Wood is the usual fuel used in these kilns, and they are frequently built with partitions, for containing the fuel and for supporting the bricks, in the form of arches, as will be presently described. The bricks must be placed in the kiln with great care, and this operation is called *setting* the kiln, and is performed by one or two men who understand the business, and to whom the raw bricks are delivered in barrows. The form of the setting is pretty nearly the same in the country kilns and in the London *clamps*, except that in the latter the arches are much smaller, because wood is only used for kindling and not for burning.

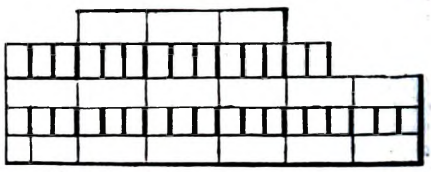
The bottom of the kiln, Fig. 1340, is laid in regular rows, of two or three bricks wide, with an

1340.



interval of two bricks between each, and these rows are so many walls extending lengthwise of the kiln, and running quite through it; they are built at least six or eight courses high, so as to give the kiln the appearance shown in the figure, which is an end view of the kiln. And this is permanent work, in kilns that have fire-places built in their floors, or it has to be formed every time the kiln is set, when it has a flat bottom. The intervals between the walls are laid first with shavings, or brushwood, or anything that will kindle easily, then with larger brushwood cut into short lengths, that it may pack in a compact manner; and lastly, with logs of split wood. This done, the over-spanning or formation of the arches is commenced; for this purpose every course of bricks is made to extend 1½ in. beyond the course immediately below it, for five courses in height, taking care to *skintle* well behind, that is, to back up, or fill up with bricks against the over-spanners. An equal number of courses, on the opposite side of the arch, is then set as before, and thus the arch is formed, which is called rounding, and is a nice and important operation, for if the arch fails or falls in, the fire may be extinguished, or many of the bricks above the arch may be broken. The intermediate spaces between the arches are now filled up, so as to bring the whole surface to a level, and then the setting of the kilns proceeds with regularity until it obtains its full height. In setting the kiln, not only in its body, but in the arches also, the ends of the bricks touch each other, but narrow spaces must be left between the sides of every brick for the fire to play through, and this is done by placing the bricks on their edges, and following what is called by brick-makers the rule of three upon three, reversing the direction of each course, as shown in Fig. 1341. The kiln being filled, the top course is laid with flat bricks, so disposed that one brick covers part of three others; which process is called *platting*.

1341.



*Indian Kiln.*—There are various methods in practice in India of filling and firing a kiln of the same construction as the above.

1st. Laying alternate complete layers of wood fuel and of bricks, the flues passing only 5 or

6 ft. into the interior of the kiln, all the rest of the floor being occupied by the first layer of fuel.

2nd. Arranging the bricks in a second set of flues five or six courses above the first, and crossing them at right angles; and so on with flues alternately in these two different directions to the top; or,

3rd. Having, as before, one series of flues at bottom, and above alternate complete layers of bricks and fuel.

*Firing.*—The kiln being filled, the *firing* succeeds, and this is a most delicate operation, and one that requires much experience. The fuel is kindled under the arches, and requires close watching and attendance, for being in a large body, it would burn violently and produce a sudden heat such as would crack and spoil the lowest bricks. To check the burning, the arch holes or mouths are closed with dry bricks, or even smeared with wet clay, in order to prevent the entrance of air and the rapid combustion that would ensue. The fire must be made to smother rather than burn, as in making charcoal, in order that by its gentle heat it may evaporate the humidity that remains in the bricks, and produce drying rather than burning. This slow fire requires to be kept up about three days and three nights, by occasionally opening the vents to supply air and additional fuel, and closing them until the fire *gets up*, as the workmen call it, that is to say, until it has found its way through all the chinks and openings between the bricks, and begins to heat those at the top of the kiln. To ascertain the progress of the fire, the top of the kiln must be watched, and as soon as the smoke changes colour from a light to a dark hue, the drying is complete, and the fire may be urged. The first, or white smoke, called water-smoke, is in fact little else but the steam of the water while evaporating, and when that is gone, the real smoke of the fuel succeeds. Now the vents may be opened to admit full draught, and a strong fire kept up for from forty-eight to sixty hours; but the heat must not be white or so strong as to melt or vitrify the bricks, and whenever it appears to be increasing too rapidly, the vent must be partly closed. By this time the kiln, if it contains thirty-five courses, will be found to have sunk about 9 in.; but the stronger the clay the more it will shrink, and it is by this sinking that the workman knows when the kiln is sufficiently burnt. The experience of burning a few kilns will show how much the clay of that particular place yields to the firing. When it is thus ascertained that the kiln is ready, the vent-holes, and all other chinks through which air can enter, are carefully stopped with bricks and clay. In this state it remains until the bricks are cold enough to be taken down, when they are distributed for use.

From the nature of the above process it will be evident that bricks of very different qualities must be found in the same kiln; for as the fire is all applied below, the lower bricks in its immediate vicinity will be burnt to great hardness, or perhaps vitrified; those in the middle will be well burnt; and those at the top, which are not only most distant from the fire, but more exposed to the open air, will be too little burned; consequently, if they can be used, they must be reserved for inside work that is not exposed to the weather, or they will soon fail and crumble to pieces.

*English Clamp.*—In the English method of *open clamp* burning, without any kiln, the piling and disposition of the bricks is the same as above described, except that the bottom arches are much smaller, as they are only intended to contain brushwood to produce the first kindling, and not for the future supply of fuel. No fuel is used except the *breeze* cinders and small coal, and this is distributed, by means of a sieve with wires about half an inch apart, over every course, as it is laid near the bottom, and over every alternate course, or every third course higher up in the kiln. The first layers of this fuel are from 1 in. to 1½ in. in thickness, but they diminish as they ascend, because the action of the heat is to ascend; consequently, there is not the same necessity for fuel in the upper as in the lower part of the kiln. The brushwood in the bottom ignites the lower stratum of fuel, and from the nature of its distribution, the vertical as well as horizontal joints will be filled with it and thus the fire gradually spreads itself upwards, and the whole clamp is nothing but a mass of bricks and burning fuel. The heat is therefore much more generally distributed throughout the whole mass, and in order to confine it, the entire outside of the clamp is thickly plastered with wet clay and sand, the bottom holes being opened or shut, as occasion may require, for regulating the draught of air.

Notwithstanding the heat is much more equally distributed throughout this form of kiln, yet the outside bricks all around receive very little advantage from the fire, and are never burnt; but being on the outside they are easily removed, and are reserved for the outside casing of the next clamp that may be built; and being then turned with their unbaked sides inwards, some of them become available. On taking down the clamp, the bricks are assorted into three separate parcels or varieties, according to their perfection and goodness. Those that are burnt very hard and have not lost their figure or shape, may be selected for arches. The main body of well-burnt bricks are called *stocks*, and those which are imperfectly burned are called *place* bricks.

These several varieties of brick have each a separate price, the best being worth twice as much as the worst. If the fire has not been carefully attended to, and has been permitted to get too violent, some of the lower bricks will become distorted by partial fusion, and may fuse and adhere together, when they are called *clinkers*, and are useless for building purposes, but form an excellent road material.

A coal clamp of 100,000 bricks rarely burns out under a month. There is a great saving of fuel in burning large clamps but where time is an object, small clamps ought to be made. The bricks ought not to be opened out before they are thoroughly cool, as they are apt to crack by the breeze playing upon them when hot. The amount of coal to be used depends upon the quality of the fuel, and the degree of hardness to which it is wished to burn the bricks. Six hundred and fifty or seven hundred maunds of moderately good coal ought to be sufficient to burn 100,000 bricks; a great deal, however, depends also upon the clay; a light sandy clay, such as is found by river sides, takes less fuel than a hard, strong clay.

A maund is an Indian weight, varying in different localities from 24 to about 82 lbs. avoirdupois.

The Madras maund is 24 or 25 lbs.; the Bombay maund 28 lbs.; the Surat maund 41 lbs.; and the bazaar maund 82⅔ lbs.

In London, close instead of open clamps are employed, no spaces being left between the bricks. Each brick contains in itself the fuel necessary for its vitrification; the breeze or cinders serving only to ignite the lower tiers of bricks, from which the heat gradually spreads over the whole clamp.

*Indian Clamp.*—The native clamp, or *pajáwah*, is an arrangement for brick-burning in the open air, somewhat resembling the English *clamp*. The bricks and fuel are laid alternately, the former in courses of four or five bricks, the latter of 2 or 2½ ft. in thickness, the proportion of fuel being diminished towards the top. The whole is generally built with one side abrupt and nearly vertical, and with a long slope on the other. The fuel consists of dry grass, wooden chips, *khát* (manure), *koorah* (litter, miscellaneous dry sweepings), and *oopla* (dried cow-dung), and very generally a layer of wood under all.

The form of the *pajáwah* is generally triangular; its floor smooth and sloping at an angle of 15°, being lowest at the angle, where it is lighted. The upper surface slopes at an angle of about 30°, in the direction of its length.

The following is a note on brick-burning in *pajáwahs*, by Lieut. J. Finn, formerly Executive Officer of Materials at Roorkee:—The quantity of fuel used in the Hindoostanee kilns at and near Roorkee is about 6 in. thicker than the layer of bricks placed over it; that is to say, if the fuel is 3 ft. in thickness, the layer of bricks placed on the top of it should be 2½ ft. or five bricks high; each brick being 6 in. wide. A kiln now being filled at Roorkee has a layer of wood about 1 ft. deep all along the bottom, but none in the second or third tiers, excepting a small quantity at the mouth of the kiln to ensure its speedy ignition. When the kiln is ready for firing, about 1 ft. in thickness of fuel is spread all over its top, and over that 1 ft. of ashes.

The under-mentioned quantity of fuel will burn one lakh of bricks in a native kiln, namely, 325 2-bullock cart loads of *khát*, 750 maunds of *oopla*, and 100 maunds of fire-wood.

Once a kiln is filled, covered over on the top with ashes, and fired, it is not liable to injury from high strong wind; nor will a heavy fall of rain harm a kiln when in the above-mentioned state.

The size of bricks used in masonry works of the Northern Division, Ganges Canal, is 12 × 6 × 2½ in.

The sooner a Hindoostanee kiln is fired the better. When about one-third filled, the kiln ought to be lighted, for the fire will burn quicker and more equably before the fuel becomes compressed and partly decayed than it would otherwise.

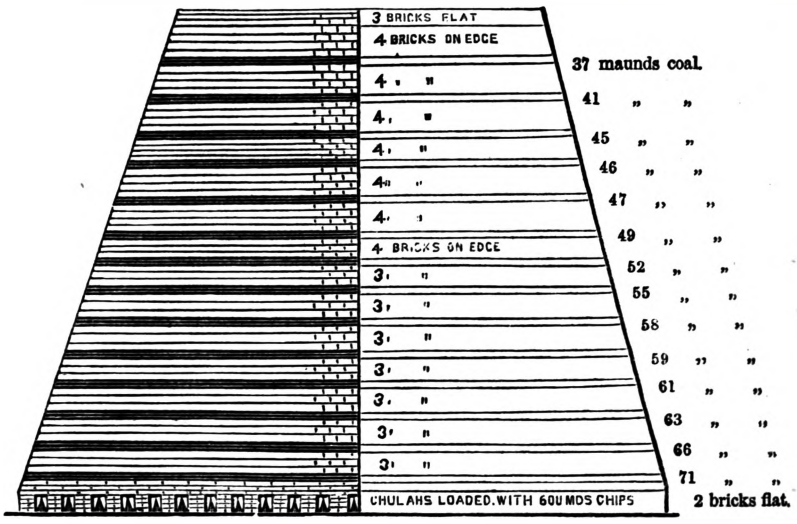
The fuel used in a *pajáwah* consists of all kinds of combustible refuse of towns and villages, and *oopla* and dung made into cakes well dried in the sun. *Oopla* and *huddy khuddy* (bones and pigs' dung) have been weighed before being put into kiln; of the former, from 1500 to 1800 maunds; of the latter, from 300 to 600 maunds; and about 6000 maunds of *koorah* (village refuse) are required for one lakh of bricks. Small quantities of wood have sometimes been put into kilns, but it proved disadvantageous, and the use of wood and *koorah* conjointly is injurious.

The time occupied in loading a kiln varies from two to three months for each lakh. Experience has convinced brick-makers in India that the sooner a kiln is fired the better. The rule is that when 40,000 or 50,000 bricks were piled into the kiln, it should be lighted; the progress of the fire being slow, any number of bricks can be piled afterwards.

Figs. 1342 to 1344 show sections of a brick clamp as burnt by Captain Sage. Contents of kiln, Fig. 1342:—Small wood and chips, 600 maunds; coal in layers, 750 maunds; bricks, 206,000. Contents of kiln, Fig. 1343:—75,000 bricks; 1185 maunds of wood.

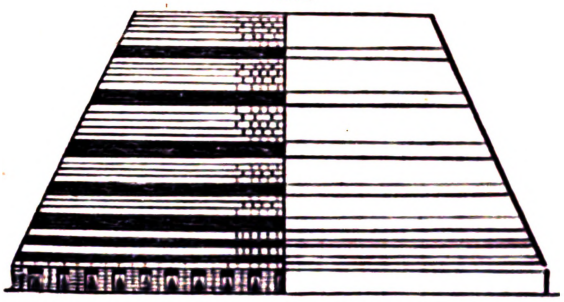
1342.

Burnt with coal at Bhoorsoot.



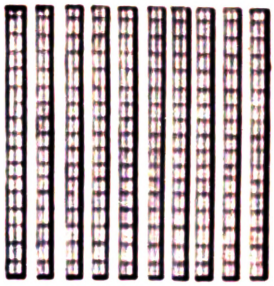

Ground Plan similar to that of Fig. 1343.

1343.



Burnt with wood at Julapoor.

1344.



Plan of Chulahs.

Various experiments were made in Bengal, and the result published by the Military Board, in 1827 and 1828, on the burning bricks in *clamps*, both with wood and coal. The clamps were built with flues as described in the English *kilns*, but smaller, and filled with well-dried chips or brushwood. For the fuel above the flues, green wood was preferred, as retarding the fire; wood-loaded kilns generally burning too rapidly, and causing great loss by vitrifying the bricks in the centre. The wood was split up into pieces not exceeding 4 or 5 in. in thickness, and so arranged as to leave level surfaces, for the layers of bricks to be laid upon. The flues were 2 ft. high and 9 in. wide, with three bricks laid flat on them, having narrow intervals to allow of the fire ascending from the flues. The clamps were finished with alternate layers of brick and fuel, the bricks being laid touching each other throughout, the interstices formed by their contraction under the great heat being sufficient to ensure the firing of the upper layers of fuel. The sides of the clamp were then built up with mud and broken bricks, well plastered with mud to exclude the air.

Besides the advantage of cheapness, coal is shown to be in many other respects superior, as fuel, to wood; the space occupied by it between the layers of brick is so much smaller, that the clamp sinks much less, and its outer casing is less deranged. The wind which interferes with the gradual and equable process of the fire is thus better kept out. The loss by breakage is likewise much less, and the bricks from being burnt more slowly are more compact. The coal should be broken into pieces not exceeding 1 in. in diameter. In kilns, likewise, coal must have like advantages over wood except as regards the greater displacement of the casing of the clamps; the permanent walls of kilns not being liable to this contingency. Kiln walls may be built of bricks plastered with mud, and repaired with the same material from time to time; they should slope on the outside about 1 ft. in 5.

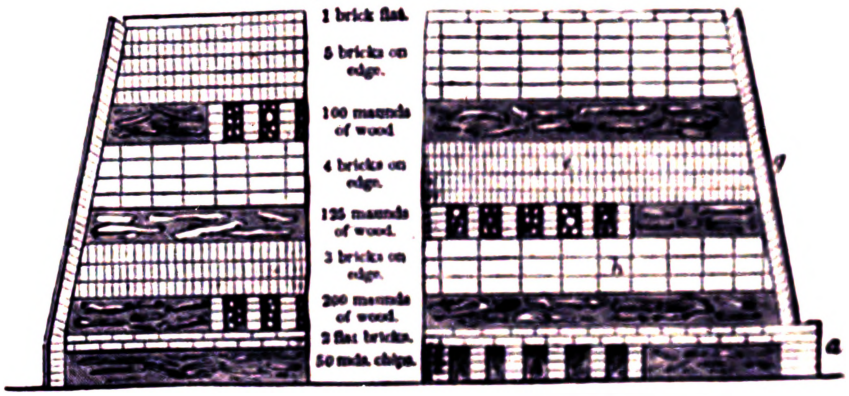
Another construction, by Capt. Bell, Figs. 1345, 1346, seems well adapted to prevent the sinking of kilns when wood is used as fuel. The wood is everywhere contained in flues, crossing each other at right angles, the walls of which are supported by layers of bricks on edge, completely covering the area of the kiln.

The ground layer of four flat bricks being laid with equidistant flues, they are filled up with light wood and dry chips, over which two bricks are laid flat; on this is formed a second set of flues, running across the ground flues, and, after filling up between the flues with wood, the whole area is built over with three bricks on edge, the length of the bricks running in the same direction with the flues and wood. The full height is formed by an alternation of flues and solid masses of bricks, as shown in Fig. 1346. Two rows of bricks laid flat seem to be requisite above *each* set of flues, to prevent the bricks on edge from falling into them, whilst the fuel is being consumed.

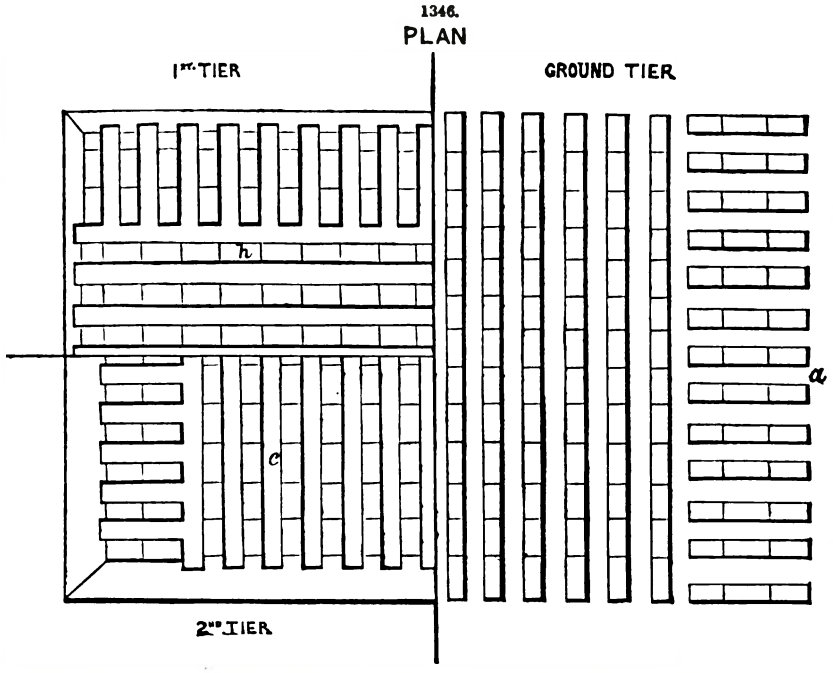
To close the clamp, extend the flue opening as at *a*, Fig. 1345, one brick in length, and cover

1345.

Brick Clamp burnt by Captain Bell at Burdwan.




Cross-Section. Longitudinal Section.




it with two flat bricks. Then build up, with one brick breadth-ways, the outer coating as at *g* (with half-dried bricks, or any kind), over which straw (well wetted) is laid on the slope from the top downwards, giving it a good coat of mud plaster. The mud should not be thickly laid on, but well rubbed into the grass. If thick, the heat of the fire and sun makes it peel off and admit the air, before the fire has gone through the kiln.

One great error appears to consist in putting large masses of wood into the *upper* tier flues: it is thus that so much material becomes vitrified. The ground flues ought to be filled (but not choked) with good dry fuel intermixed with chips, so as to communicate quickly through the whole. The wood of the first tier should be reasonably large, with some small pieces or chips; and in every higher tier in succession they should be less in size as well as in quantity; because, as all the fire and heat rise from below, the higher tier has the advantage of all the foregoing flue fires in addition to its own. Previous to its ignition, too many bricks should not be piled above wood, however great the quantity of the latter, or they will be irregularly burnt and much fuel wasted.

See BOND. BOND-COURSE. BRICKWORK. CONSTRUCTION. KILN. STONE, *Artificial.*

*Works and Papers relating to Brick-making*:—Brughat, 'L'Art du Briquetier,' 2 vols., 1861. Dobson (E.), 'On Bricks and Tiles,' 1868. Medley (F. G.), 'Roorkee Treatise on Civil Engineering.' Papers by Clift, Fothergill, and others, in the 'Trans. Inst. Mechanical Engineers.'

BRICKWORK. FR., *Maçonnerie de briques*; GER., *Mauerarbeit, Ziegelwerk*; ITAL., *Mattonato*; SPAN., *Enladrillado.*

A term used in the art of construction to denote the combination of bricks with mortar or cement.

Architects and surveyors in the neighbourhood of London adopt as their standard of measurement for brickwork the square rod of 272 ft. superficial, reduced to a thickness of 1½ brick. In the provinces and by civil engineers the cubic yard is more commonly used.

A rod of reduced brickwork of four courses to the foot in height requires 4356 bricks, and a cubic yard requires 384 bricks. When the mortar-joints are limited to ¼ of an in. in thickness, the rod of brickwork contains 258 ft. cube of bricks and 48 ft. cube of mortar; the cubic yard contains 22¾ ft. cube of bricks and 4¼ ft. cube of mortar. When the joints are ⅜ of an in. in thickness, the rod of brickwork contains 235 ft. cube of bricks and 71 ft. cube of mortar; the cubic yard contains 20¾ ft. cube of bricks and 6¼ ft. cube of mortar.

The proportions, in general, of bricks and mortar in any given quantity of brickwork vary according to the size of the bricks and the thickness of the mortar-joints. In practice, 3 cubic yards of mortar are allowed to a rod of brickwork, and 36 bushels of Roman cement with an equal quantity of sand; but when Portland cement is used there should be allowed about 38 bushels of cement to an equal quantity of sand. When the proportions of Portland cement to sand are to be as 1 to 2, 25 bushels of the former and 50 of the latter will be required for a rod of brickwork. 126 gallons of water are usually allowed to a rod of brickwork to slake the lime and mix the mortar. Cement requires rather more water, particularly Roman cement, which absorbs it very rapidly.

The weight of bricks varies considerably, some weighing only 5 lbs. and others 7½ lbs., and in some cases as much as 9 lbs. each. For the purpose of calculation, however, the weight of a rod of brickwork just built may be taken at 16 tons, which will probably be reduced to 15 tons when the work becomes thoroughly dry.

Some bricks are very porous, and will absorb more than *one-fifth* of their weight of water, if immersed in it soon after their withdrawal from the kiln. When bricks are exposed to the rain,

which is usually the case when stacked for building, they take up a large quantity of water, which they never entirely part with. Ordinary London stocks absorb about one-fifteenth part of their weight of water in the process of building, most if not all of which they lose again by evaporation.

Brickwork built with Portland or Roman cement requires a weight of about 30 tons a superficial foot to produce fracture by compression; and when built with blue lias lime mortar, thoroughly set, it requires about 20 tons. When Portland cement is used, fracture almost invariably takes place in the bricks; but with Roman cement, particularly when used with moist sand, fracture sometimes occurs in the cement itself, and still more frequently when mortar is the cementing material—a result naturally to be expected from a consideration of their relative degrees of strength. See CONSTRUCTION.

BRICK-NOGGING. FR., *Remplissage de briques d'un châssis de charpente*; GER., *Füllmauerwerk*; ITAL., *Muratura di riempimento*.

Brick-nogging or brick-nog partition, is a description of walling consisting of brickwork and timber. It is usually made of the width or thickness of a brick, and is framed similar to a wood partition, the quarters or studs being 2 or 3 ft. apart, with brickwork filled in between them: horizontal pieces, called *nogging-pieces*, are also laid in regular tiers between every two courses of bricks. Although brick-nogging does not add to the strength of a partition, it is some little security against fire.

BRICK-TRIMMER. FR., *Enchêtrure de briques d'une cheminée*; GER., *Gurt bogen im Kamin*; ITAL., *Arco di mattoni*.

Brick-trimmer is the term applied to a brick arch abutting against the wood trimming just in front of a fire-place, and used to support the hearth. See Fig. 271, p. 121.

BRIDGE. FR., *Pont*; GER., *Brücke*; ITAL., *Ponte*; SPAN., *Puente*.

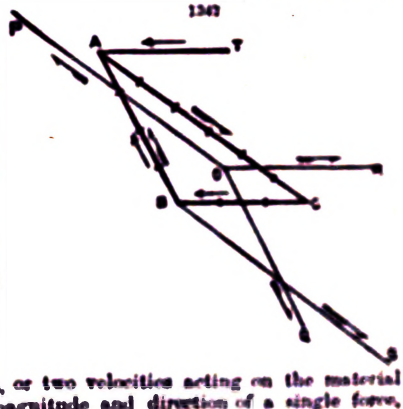
Bridges are structures, usually of wood, stone, brick, or iron, erected over rivers or other watercourses, or over ravines or railroads, to make continuous roadways between banks.

A *draw-bridge* is a bridge so constructed that a part of it may be temporarily removed, or drawn aside, to allow the passage of vessels; called also a *swing-bridge*, or *bascule-bridge*, when the part which opens turns *laterally* on a centre or end pivot. In mathematics and mechanics the terms *laterally*, *lateral*, and *laterality*, or the quality of having distinct sides, are often misapplied. *Lateral*, as an adjective, signifies proceeding from, or attached to, the sides; as, the lateral branches of a tree; lateral shoots; or as an adjective this term may signify, directed to the side; as, the lateral view of an object. Sometimes, in mathematics, an equation of the first degree is designated as a *lateral equation*. In mechanics, *lateral pressure or stress* is a pressure or stress at right angles to the length, as of a beam or bridge; distinguished from *longitudinal pressure or stress*. And *lateral strength* is that strength which resists a tendency to fracture arising from lateral pressure.

In the sequel, we treat of the construction and mechanical requirements of *Draw*, *Girder*, *Lattice*, *Truss*, *Tubular*, *Flying*, *Suspension*, *Skew*, *and Trestle bridges*; after we have examined the nature and actions of pressures, thrusts, and tensions.

*Equilibrium of Pressures, Thrusts, and Tensions;—Forces.*—Anything which cannot be presented to the senses must be represented conventionally, or no idea of it can be entertained by the mind. We have no objection to represent the magnitudes and directions of forces, velocities, pressures, thrusts, and tensions by straight lines of different lengths, and in different positions: but we object to the careless manner in which writers on mechanics represent forces, pressures, velocities, &c., by straight lines, triangles, and parallelograms, out of all proportion, and often, too, without the least regard to the action, direction, or nature of the force considered. In the article on BOILERS, p. 425, we gave a conventional signification to the areas of plane figures, but in the present article the sides and angles of triangles, parallelograms, and other plane figures are employed to give an idea of mechanical operations and combinations, where the *principle of work* does not apply, as rest and not motion is here principally considered.

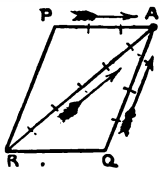
When comparing graphically the action of statical forces, it would be convenient to put a split arrow (⟶) to designate the directions of tensions, the arrow without feathers (⟶) to point out the directions of thrusts, while the complete arrow (⟶) might be applied to forces in general. If three forces P, Q, R, Fig. 1347, be represented by the abstract numbers, 6, 4, 3, respectively, then if A B C be a triangle whose side A C = 6, A B = 4, B C = 3, equal parts taken from any scale of equal parts; let P O be a tension equal and parallel to A C, Q O a tension equal and parallel to A B, R O a tension equal and parallel to B C; these three tensions will keep the point O at rest. Three thrusts represented by three lines P O, O Q, O R, whose lengths are as 6, 4, and 3, respectively, and parallel to the sides of the triangle A B C, will also keep the point O at rest. Take A T equal and parallel to B C, then the two thrusts represented in magnitude and direction by the lines T A, B A, and the tension represented in magnitude and direction by the line A C, will keep the point A at rest. Again, if B S be equal and parallel to A C, tensions represented by A B, B S, and a thrust, C B, will keep the point B at rest.




Let P A, Q R, Fig. 1348, be a parallelogram, if P A, Q A, represent the magnitudes and directions of two forces, two pressures, two thrusts, two tensions, or two velocities acting on the material point A; then the diagonal R A will represent the magnitude and direction of a single force, pressure, thrust, or tension, equivalent to the operations represented by the lengths and directions

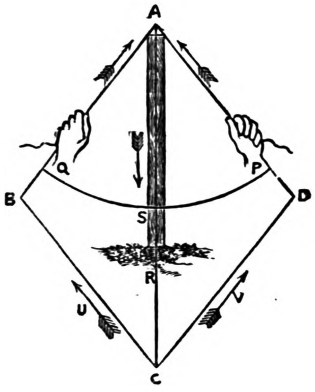
of P A and Q A. Such imaginary parallelograms form a great portion of the stock-in-trade of writers on mechanics. We have introduced Figs. 1347 to 1351 to illustrate the manner in which the different forms of arrows may be applied with advantage. The properties pointed out in Fig. 1347 depend upon the truth asserted of the parallelogram P A Q R, Fig. 1348, which we will prove presently.

1348.

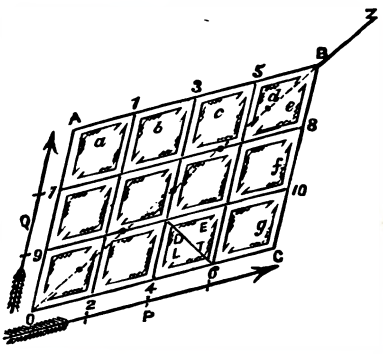



*The principle of sufficient reason; first employed by Archimedes in demonstrating the fundamental propositions of mechanics.*—Let P and Q, Fig. 1349, be two equal forces acting in the same plane on the rigid perpendicular prop A R, the point R fixed; further, let these forces P, Q, make equal angles, S A D, S A B, with the prop A R, which may turn to the right or left round the fixed point R. But as the forces P and Q and the angles B A S and D A S are also equal, there is no reason why the post A R will turn to the right or left; hence it will stand, and the two tensions will be neutralized by the perpendicular thrust of the post A R. This we call a mechanical demonstration, and the principle applied *the principle of sufficient reason.* For there is no reason why the post under consideration should fall to one side more than another, hence we conclude it will fall to neither side. Let A B C D be a parallelogram whose sides are all equal; if the length of the line A B be taken to represent the magnitude of the force Q, then A D will truly represent the force P; and two other equal forces, V and U, applied to the point C, represented in magnitude and direction by the lines C D, C B, will counteract the forces P and Q the same as the post A R, the diagonal A C being rigid. The principle of sufficient reason applies here as in the former case. It is evident that any number of equal forces may be applied in the directions of the arrows, P = Q = V = U, without disturbing the form of the equal-sided parallelogram A B C D, or the position of the rigid diagonal A. The abstract truth of the parallelogram of forces, thrusts, tensions, pressures, or velocities may be established by reasoning as follows: Let A B C O be a parallelogram; when its sides can be expressed by numbers, it may be divided into small parallelograms, the sides of which are all equal to one another. We have selected a very simple case, and taken O C = 4 equal parts and A O = 3 of the same parts. Let the force P be to the force Q as $m$ to $n$; in the present example, P : Q :: 4 : 3.

1349.



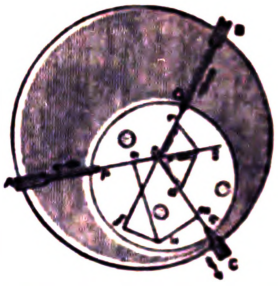

1350.




The forces P and Q applied to the material point O in the direction O C, O A, may evidently be represented by the lines O C, O A; if a new set of forces, represented by the small parallelograms, be introduced as represented by the arrows in the figure, the combined action of the forces P and Q will not be interfered with, nor will the equilibrium of the figure be disturbed. Take, for example, the small equal-sided parallelogram D E T L, and for a moment suppose the diagonal D T rigid; then *the principle of sufficient reason* applies to the forces introduced, and no disturbance takes place. Let us now view these forces under another aspect. The forces along the sides of the small parallelograms on the line C O are equal to the force P, but in a contrary direction, and hence destroys it. The forces represented on the line 9, 10, also destroy one another. This may be said of the forces on the line 7, 8; but the forces on the line A B are not neutralized, and are exactly equal to the force P, but applied to the point B in the diagonal O B. Again, the forces along the sides of the small parallelograms on the line A O are equal to the force Q, but in a contrary direction, and hence may be said to destroy it. The forces pointed out by the arrows on the line 1, 2, also neutralize one another; the same may be said of the forces supposed to be introduced on the line 3, 4, and so on, until we arrive at the forces pointed out on the last line B C, which, together, are exactly equal to the force Q, but applied to the point B in the diagonal O B. According as the equal parts be long or short, the point B will change its position; but it will always be in the diagonal O Z, and the forces $a + b + c + d$ = P and $g + f + e$ = Q will in all cases have their resultant position in the diagonal O Z. Had we supposed the force P to be divided into 1000 equal forces, O C would be represented by 1000 equal parts, and O A = Q would then be composed of 750 such parts, and our reasoning on the 750000 equilateral small parallelograms of forces would result in the same conclusion. The equilibrium of forces and pressures may be illustrated in a practical way by a simple mechanical contrivance, represented in Fig. 1351, easily constructed. Suppose P Q R to be a slate or board rolling freely upon three equal spherical balls placed on a horizontal table A B C. If any three points, P, Q, R, be taken in the surface of the plane movable on the balls, and cords, A P, B Q, C R, be attached, passing over the pulleys,

with a different amount of weight attached to the other ends—the ends with the weights attached are not represented in the cut—the board P Q R will roll upon the balls, and ultimately come to rest upon the table A B C, where the three forces destroy each other. When this experiment is carefully made, it will be found that the directions of the forces A P, B Q, C R, meet in the same point O. Again, from any scale of equal parts take O $r$ = the pounds in the force drawing the cord Q B, and from the same scale of equal parts lay off O $a$ = the pounds drawing the cord R C; then, if the parallelogram O $r$ $s$ $a$ be constructed, the diagonal O $s$ will be in the direction of the third force acting over the pulley A. It will be further found that the units of length in O $s$, the diagonal, will = the weight or force acting by the cord A P.

1351



If O $a$ = 22 equal parts, O $r$ = 28, and O $s$ = 26, all measured on the same scale of equal parts, then, if 7 lbs. be attached to the cord Q B, and 5½ lbs. to the cord R C, a weight of 6½ lbs. must be attached to the cord A B to maintain this equilibrium. When forces are thus represented by a parallelogram, as O $r$ $s$ $a$, the forces represented by the sides are called the component forces, while the force represented by the diagonal is denominated the resultant. Another experiment may be instituted to determine the intensity of forces by this simple apparatus. Instead of three forces being applied to the board, let there be any number; and suppose H to be any point taken in the movable plane P Q R, and from H let fall perpendiculars H $n$, H $m$, H $f$, and so on, in the directions, or directions produced, of the forces; then the units of length, taken from any scale of equal parts, multiplied by the pounds in the corresponding force, will be what is termed the *moment* of that force tending to turn the board or movable plane upon the point H. This being done, the principle denominated *the principle of the equality of moments* may be verified by experiment. Here but three forces are applied, but any given number may be introduced; in the present case,

$$\text{H } f \times \text{B lbs.} + \text{H } m \times \text{C lbs.} = \text{H} \times n \text{ A lbs.}$$

The student must not confound *the principle of the equality of moments*, just defined, with the intensity of forces usually considered by examining the motions they produce, or the spaces passed over when the motions are uniformly accelerated. It has been before shown that, generally,

$$(\text{Force}) = \frac{\text{W}}{g} \frac{v}{t}; \qquad [1]$$

$t$ being an extremely small portion of time, denominated an element, during which the velocity $v$ is generated. The above formula shows that if, by observing the laws of motion, we know for each instant the value of the ratio $\frac{v}{t}$, we shall then have that of the corresponding effort designated (Force) in the above formula. Suppose we know, from experiment, that the motion is uniformly accelerated, we have, for the space S, $\text{S} = \frac{1}{2} \text{V}_1 \times \text{T}^2$, in which

$$\text{V}_1 = \frac{\text{V}}{\text{T}} = \frac{v}{t}, \text{ as in [1]};$$

$$(\text{Force}) = \frac{\text{W}}{g} \frac{2\,\text{S}}{\text{T}^2} \qquad [2]$$

Suppose a locomotive weighing 10 tons (22400 lbs.) runs, with a uniform accelerated motion, a distance of 154·4 ft. in four seconds, required the force in lbs. capable of imparting this accelerated motion, the friction of the rail not being considered?

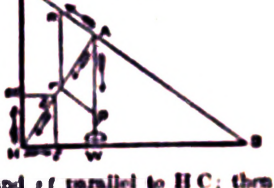
$$\text{From [2] (Force)} = \frac{22400}{32\frac{1}{6}} \frac{2 \times (154 \cdot 4)}{4^2} = 13440 \text{ lbs.}$$

(See pp. 93, 94, 116, Byrne's 'Essential Elements of Mechanics.')

*Definition.*—A bar is called a *strut*, or a *tie*, according as a thrust or a pull is exerted along its line of resistance.

Let C H B A, Fig. 1352, be a *skeleton diagram* representing centres and lines of resistances, H B a platform with a load W = 47 cwt. upon it, C B a chain supporting both load and platform; find, by construction, the tension of the chain and the amount and direction of the pressure upon H, the point about which the platform turns, the weight of which being neglected?

1352



Draw W A perpendicular to H B, intersecting the chain in A: join A and H, and, from a scale of equal parts, lay off A $p$ = 47, a part for each lb. in W, which acts in the direction A W. Draw $p r$ parallel to C B, and $r n$ parallel to A W, the parallelogram A $n$ $r$ $p$ gives the required tension and thrust. In the diagram A $r$ = 37 equal parts, answering to 37 cwt., the pressure on the hinge H; A $n$ = 26 equal parts, answering to 26 cwt., the pressure tending to break the chain. Take H $s$ = A $r$, draw $s m$ parallel to W H, and $s t$ parallel to H C; then H $t$ gives the thrust of W against the wall, which is represented by H C, and H $m$ shows the pressure in the direction of the stationary wall H C.

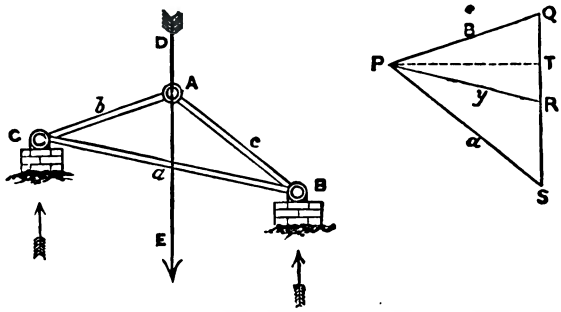
Given a triangular frame, A B C, Fig. 1353, loaded and supported both in the direction of the vertical line D E; find the relative proportions of the forces?

Put A, B, C, for the three joints, and $a$, $b$, $c$, for the three bars. These things being premised, from any point, P, draw P R, P Q, P S, parallel to the lines of resistance $a$, $b$, $c$, respectively across these lines the vertical line Q R S, then the following proportions apply to the forces:—

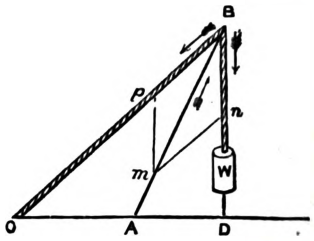
Load on A : supporting force at B : supporting force at C : : stress along $c$ : stress along $a$ : stress along $b$; so stand in order and proportion the lines Q S : S R : Q R : P S : P R : P Q.

Out of the six proportions thus succinctly stated, to illustrate, we shall single out one: Load on A : supporting force at B :: Q S : S R.

1353.




1354.




Let a pole, A B, Fig. 1354, be supported by a cord, C B, and carry a weight, W; required the tension of the cord, and the pressure on the pole?

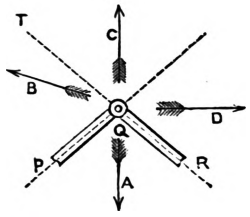
From B to $n$ lay off equal parts, equal to the units of weight in W; draw $m\,n$ parallel to C B, intersecting B A in $m$; draw $m\,p$ parallel to B $n$; therefore the units in B $p$ will give the tension of the cord C B, and the units, measured on the same scale of equal parts, in the diagonal B $m$, will give the thrust on the pole A B.

Struts may be distinguished from ties thus:—In Fig. 1355, P Q, Q R, represent two bars of a frame meeting at the joint Q; produce the lines of resistance beyond Q to S and T. Then a force in the direction of the arrow A, between the angle P Q R, both bars are struts; if the force be in the direction of the arrow B, in the angle T Q P, then P Q is a strut, and Q R a tie. Again, when the force is applied in the direction of the arrow C, both bars are ties; and, lastly, when the force is in the direction of the arrow D, in the angle S Q R, then P Q is a tie, and Q R is a strut.

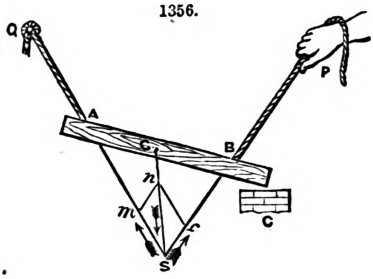
A beam, A B, Fig. 1356, resting on a wall, C, and supported by a cord, Q A; it is required to determine the direction and tension of the cord B P, so that the beam may not change its position when the wall C is removed, the point B being also given?

Let G be the centre of gravity of the beam, through which draw the vertical line G $s$ in the direction of the plumb line, to meet Q A produced in $s$, join $s$ B, and produce it; B P in the direction of $s$ B shows the direction a cord fastened at B must take so that the beam will not change its position when the wall C is removed.

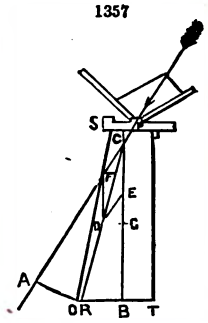
1355.




1356.

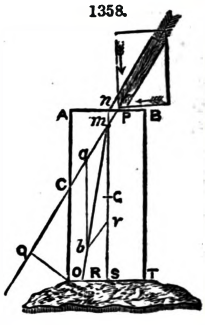



1357




To find whether a pier, or other support, S T, Fig. 1357, will overturn by the action of a force P, or the resultant of several forces operating in a given direction, P C A. Produce the direction of the force P, and let fall the perpendicular O A, then, in order that the structure may not turn on the point O, we must have, G being the centre of gravity, weight of the structure S T × O B greater than P × O A. When (weight S T) × O B = P × O A, the pier will be on the point of turning on the edge, O.

1358.




*By Construction.*—Let B C be the vertical line passing through the centre of gravity of the pier or pillar, intersecting the direction of the force P in the point C; from a scale of equal parts take C F = the units in the pressure P, and from the same scale take C E = the units in the weight of the structure, S T; complete the parallelogram of forces, C D E F, then C D will give the amount and direction of the single force tending to overturn the structure or support, S T. When C D produced intersect the base within the edge O, the structure will stand; but should the point of intersection, R, fall without the base, the structure must fall.

A T, Fig. 1358, is a pier, or buttress, weighing 860000 lbs., P a pressure of 320000 lbs.; A B = O T = 6·6 ft.; O A = B T = 15 ft.; the cross-section A B T O is a rectangular parallelogram, of which G is the centre of gravity. The direction of the force P tending to overturn the structure cuts A B 4 ft. from A, and A O at C, 7 ft. from A.

It is required to find whether the structure will stand or fall, and what will be the amount of the pressure, P, just sufficient to overturn the solid mass of which A B T O is a cross-section?

$$C P = \sqrt{A C^2 + A P^2} = \sqrt{7^2 + 4^2} = 8{\cdot}0622577.$$
$$C P : P A :: C O : O Q,$$
$$\text{or, } 8{\cdot}0622577 : 4 :: 8 : 3{\cdot}969 = O Q.$$

Since A T is a rectangular parallelogram, a vertical line, S G m, passing through the centre of gravity, G, divides the base O T into two equal parts. ∴ O S = S T = 3·3 ft.; then we can compare moment of the wall = 860000 × O S = 2838000. Moment of the pressure = 320000 × O Q = 1270080; 2838000 being greater than 1270080, the structure will stand.

Putting $x$ for the pressure that will just overturn it, acting in the direction of P, then,

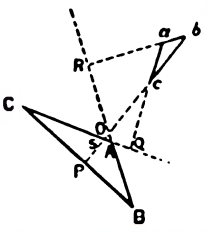
$$x \times O Q = 2838000. \quad \therefore x = \frac{2838000}{3{\cdot}9069} = 715022 \text{ lbs.}$$

If P = 715022 lbs., the point R will coincide with the point O on the outer edge of the structure.

*Geometrical Proposition.*—If the sides, or the sides produced, of one triangle, $a$, $b$, $c$, Fig. 1359, be respectively perpendicular to the sides, or sides produced, of another, A B C, these triangles are similar. $a$ Q, $b$ P, $b$ R, represent the three perpendiculars, angle C + C S P = a right angle, angle $c$ + $c$ S Q = a right angle; but angle C S P = angle $c$ S Q, ∴ angle $c$ = angle C.

In the same way the angle $b$ may be shown to be equal to the angle B; and consequently the angle $a$ = A.

1359.




1360.

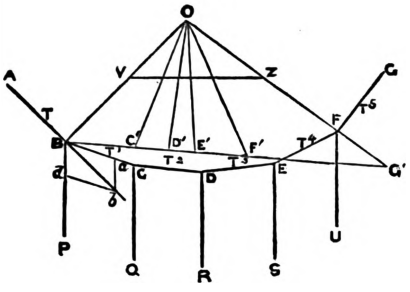
*Funicular Polygon.*—Funicular polygon is the term employed to designate a polygon formed of rods, chains, or cords, whose angular points are solicited by any forces whatever. The equilibrium of such a system of thrusts, tensions, &c., are subject to rules easily determined. First, let us suppose that the polygon has not all its sides in the same plane, and is represented by the contour, A B C D E F, Fig. 1360. Let P, Q, R, S, T, . . . . be the forces acting upon each of the summits A, B, C, D, E; the respective tensions of the sides A B, B C, C D, D E, E F, represented by T, $T_1$, $T_2$, $T_3$, . . . . respectively. If the entire polygon is in equilibrium, it must be so for all the summits separately, and since $T_1$ must be equal and opposite to the resultant of T and P, it follows that any two sides uniting at the same summit, and the direction of the force acting upon this summit, must be in the same plane; and the tension $T_1$ must be equal and opposite to the resultant of the force Q and tension $T_2$, and consequently in substituting at the summit C, for the tension T, its two components P and T, the forces P and Q, and the tensions T and $T_1$, supposed to be transferred to the point C, parallel to themselves, must be in equilibrium. We see also that the forces P, Q, R, and the tensions T and $T_2$, supposed to be transmitted to the summit D in parallel directions, must then produce an equilibrium. By continuing this process, we arrive at the conclusion, for the equilibrium of the funicular polygon, that when all the external forces and the tensions of the extreme sides are regarded as transferred parallel to themselves to any summit, they must necessarily produce an equilibrium there. These remarks are independent of the direction of the forces and the nature of the sides, and are applicable when the sides are subjected to efforts of compression instead of tension, with the reservation solely that the sides be sufficiently rigid to resist the compressions, without a change of form. When the forces soliciting the funicular polygon are weights, in which case the forces P, Q, R, S, . . . . are all vertical and parallel, and the polygon necessarily in one plane; for, the direction of each force, and those of the two sides meeting at the summit, are in the same vertical plane; and, as through one side we can draw but one vertical plane, it follows that the two vertical planes, containing the same side of the polygon, are coincident, and so for the other sides. Again, since all the external forces P, Q, R, . . . . and the tensions T, $T_4$, of the first and last sides are in equilibrium, T and $T_4$ must also be in equilibrium with the single resultant of all the parallel forces.

*Determination of the Tensions by a Graphical Construction.*—If, in accordance with the preceding views, we describe upon the side A B, produced from any convenient scale of equal parts, a length equal to the tension T, and construct the parallelogram B $a$ $b$ $d$, Fig. 1361, the side B $a$, measured on the same scale of equal parts, will represent their tension, $T_1$, of the side B C, and the side B $d$, the external force P. Then, if we draw through the point B, for example, a line B $G^1$ perpendicular to the directions of the forces P, Q, R, . . . . upon which lay off B $C^1$, $C^1$ $D^1$, $D^1$ $E^1$, $E^1$ $F^1$, $F^1$ $G^1$, proportional to the forces P, Q, R, S, T, and from the same point erect the line B O perpendicular to A B with a length proportioned to the tension T, or to B $b$, the triangle B O $C^1$ having two sides, B O, B $C^1$, respectively perpendicular and proportional to the sides B $b$ and B $d$ of the triangle B $b$ $d$, must be similar to it by the geometrical proposition preceding. Then the third side, O $C^1$, of the first will be proportional to the third side, $b$ $d$ or B $a$, or to the tension $T_1$, and will be perpendicular to the side B C of the polygon; the following triangle will be in the same condition, in relation to the side C D, to the force Q, and the tension $T_2$, which will be proportional to the side O $D^1$, and so on. Then, if the weight soliciting the different summits of the contour A, B, C, . . . . are in equilibrium, and we lay off upon a horizontal line lengths respectively proportional to these weights, and then from points of this line corresponding to each summit draw straight lines perpendicular to the directions of the sides of the polygon, all these right lines will intersect at the same point, and their lengths will be proportional to the tensions of the sides of the polygon, which will thus be determined. If a line V Z be drawn parallel to

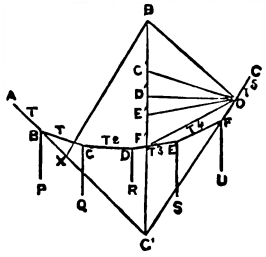
B G$^1$, the triangle V O Z answers the same purpose as the triangle B O G$^1$. The triangle B O G$^1$, Fig. 1362, expresses the same relations as the triangle B O G$^1$, Fig. 1361, B G$^1$ being taken equal to the sum and in the direction of the forces P, Q, R, . . . . B O is drawn parallel to the direction of T, and B X parallel to the direction of $T_1$; G$^1$ X gives the tension of T, and G$^1$ O the tension of $T_1$, both measured on the same scale of equal parts as B G$^1$. O B is parallel to T or A B; O C$^1$ is drawn parallel to B C; O D$^1$ to C D; O E$^1$ to D E; O F$^1$ to E F.

We have been very particular to pass nothing over that might make the proper relations and actions of forces, thus circumstanced, clear to the mind of the student, since the proper arrangement of thrusts and tensions, the action of braces, struts, and ties, in bridge-building, roofing, and in all sorts of lattice-work, designed to combine strength with lightness, depend upon the extension of the simple principles here presented.

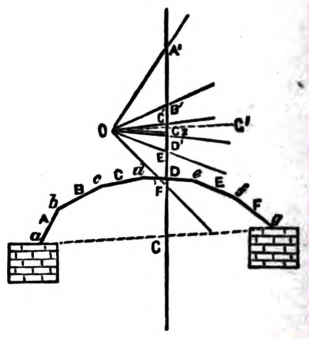
1361.




1362.




1363.



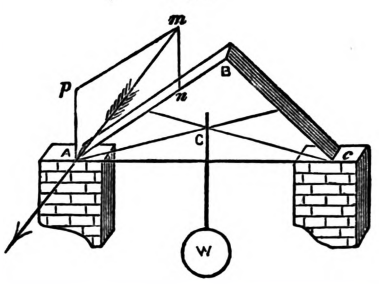

If the same Fig. 1362 be inverted, then such frame, Fig. 1363, consists chiefly of struts, and is, therefore, unstable unless their ends are made fast by suitable stays. In a polygonal frame loaded and suspended vertically, represented by the skeleton diagram, Fig. 1362, the bars which are struts in Fig. 1363 become ties, and the frame is stable and yet flexible.

The diagram of forces for Fig. 1363 may be constructed as follows:—Suppose the polygonal frame loaded vertically and supported vertically, let A, B, C, D, . . . . be the bars; $a, b, c, d, \ldots$ the joints of which $b$, $c$, $d$, $e$, $f$, are loaded, $a$ and $g$ are supported. Take any convenient point, as O, draw O A$^1$ parallel to A; O B$^1$ parallel to B; O C$^1$ parallel to C; O D$^1$ parallel to D; O E$^1$ parallel to E; O F$^1$ parallel to F; and O G$^1$ parallel to G. Then draw the vertical line A$^1$ F$^1$ crossing the lines O A$^1$, O B$^1$, O C$^1$ . . . . Then if the whole load on the frame be represented by A$^1$ F$^1$, the parts into which A$^1$ F$^1$ is cut by the lines O A$^1$, O B$^1$, O C$^1$, . . . . will represent the fractional parts of the load that must rest on each of the joints to secure equilibrium.

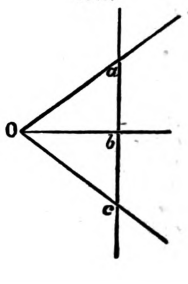
$A_1 B_1$ represents the part of the load to be applied at the joint $b$; $B_1 C_1$ the part to be applied at $c$; $C_1 D_1$ the part to be applied at $d$; and so on. The lengths of the lines O $A_1$, O $B_1$, O $C_1$, . . . . represent the resistances along the lines A, B, C, . . . . to which they are respectively parallel. The two parts $F_1 G_1$, $G_1 A_1$, into which $F_1 A_1$ is divided by the line O $G_1$ parallel to G represent the supporting forces at $a$ and $g$, that is, $F_1 G_1$ represents the supporting force at $g$, and $G_1 A_1$ the supporting force at $a$. The horizontal stress of the frame is represented by the length of the perpendicular O $G_2$ let fall from O on $F_1 A_1$. If the angles of the polygonal figure A B C D . . . . be given, the angles of the diagram of forces O $A_1$ $F_1$ are also given; hence, when the length of any one of the lines in C $A_1$ $F_1$ is also given, the lengths of the other lines are readily found by plane trigonometry, to any required degree of accuracy.

If the skeleton diagram A B C D . . . . , Fig. 1363, represent an open frame, the bar G is omitted; in this case the stress along the outer bars, represented in the diagram of forces by the lines O $A_1$, O $F_1$, must be met by oblique forces as abutments; for vertical supports would not be sufficient. This frame, being, as before observed, composed of struts, is unstable, and must be connected with suitable stays.

1364.




1365.




Let A B and B C, Fig. 1364, be a roof resting on the side walls A and C; a uniform section of this roof weighs 6000 lbs., the angle B A C = 34°, B C A = 44°; it is required to find the thrust on the points A, C, the roof being without a tie-beam; what would be the tension of a tie-beam, A C, or of a rod connecting the feet of the rafters; and also find the direction and amount of the pressure of the roof to overturn the side walls?

To construct the diagram of forces, draw O $a$, Fig. 1365, parallel to A B; O $c$ parallel to C B; and O $b$ parallel to A C, Fig. 1364.

Draw the vertical line $a\,b\,c$ = 6000 equal parts to represent 6000 lbs.

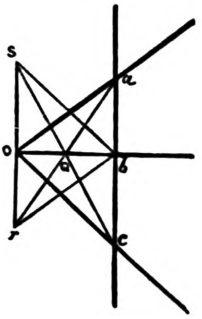
Let W = 6000 lbs. applied, suppose, at the centre of gravity, G, of the section.

$\therefore$ angle $a$ O $b$ = 34°; $b$ O $c$ = 44°. O $a\,b$ = 90 − 34 = 56°; O $c\,b$ = 90 − 44 = 46°.

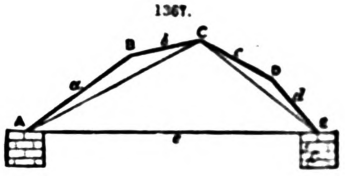
Sin. 78° : 6000 :: sin. 56° : O $c$ = 5085·35. Natural sine of 78° = ·9781476; natural sine of 56° = ·8290376. Sin. 78° : 6000 :: sin. 46° : O $a$ = 4411·44. Natural sine of 46° = ·7193398. ∴ The thrust on the point C = 5085 lbs., and the thrust on the point A = 4411 lbs. As sine of 90° : O $a$ :: sin. $a$ O $b$ : $a b$ = 2466·8. ∴ $b c$ = 6000 − 2466·8 = 3533·2. ∴ The side wall at C supports 3533 lbs. of the weight W, and the side wall at A, 2467 lbs. nearly. As sin. 90° : O $a$ :: cos. $a$ O $b$ : O $b$ = 3657·3. ∴ The horizontal thrust along the side A C = 3657 lbs.

Draw A $p$ perpendicular to A C, and = $a b$, the vertical weight at A, Fig. 1364; make A $n$ = O $a$, the thrust along the rafter A B; complete the parallelogram A $p$ $m$ $n$, and draw the diagonal $m$ A, = the amount and direction of the pressure of the roof tending to overturn the wall A. Or, to avoid complicating the figure, we reproduce the diagram of forces, Fig. 1366; taking the lines O $a$, $a b$, complete the parallelogram O $r$ $b$ $a$, then the diagonal $a r$ gives the amount and direction of the pressure as well as the parallelogram A $n$ $m$ $p$, Fig. 1364. On the lines O $c$, $c b$, construct the parallelogram O $s$ $b$ $c$, draw S $c$ = the amount and direction of the pressure of the roof applied to overturn the wall C, when the tie A C is omitted.

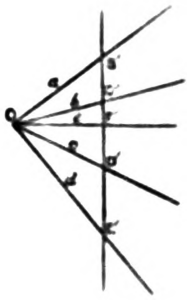
1366.




1367.




1368.




Given the skeleton diagram A B C D E, Fig. 1367, of a frame loaded and supported vertically; A E being horizontal. O $B_1$, Fig. 1368, is parallel to A B; O $C_1$ parallel to B C; O $D_1$ parallel to C D; O $E_1$ parallel to D E; and O $F_1$ is drawn parallel to A E; $B_1$ $E_1$ represents the whole load, and, being vertical, is perpendicular to O $F_1$. Now suppose the angle $F_1$ O $C_1$ = 12°, the natural tangent of which is ·21255 = $F_1$ $C_1$, when O $F_1$ = 1; the secant of this angle is 1·0223 = O $C_1$. $F_1$ O $B_1$ = 37°; $F_1$ O $D_1$ = 25°; $F_1$ O $E_1$ = 50°; then the comparative lengths of the lines in the diagram of forces will stand thus:—

| | | Tangent. | | Secant. |
|---|---|---|---|---|
| O $F_1$ = 1; | $F_1$ $C_1$ = | ·21255 | .. .. | O $C_1$ = 1·0223 |
| | $F_1$ $B_1$ = | ·75355 | .. .. | O $B_1$ = 1·2521 |
| | $F_1$ $D_1$ = | ·46630 | .. .. | O $D_1$ = 1·1033 |
| | $F_1$ $E_1$ = | 1·1917 | .. .. | O $E_1$ = 1·5557 |

The frame is vertically loaded with 5000 lbs; how is it distributed, and what are the particulars of its action when the forces balance each other?

$F_1$ $B_1$ + $F_1$ $E_1$ = 1·94525 = 5000 lbs.

1·94525 : 5000 :: 1·0223 : 2628 lbs. stress along the bar $b$ or B C
1·94525 : 5000 :: 1·2521 : 3218 lbs. stress along A B or bar $a$.
1·94525 : 5000 :: 1·1033 : 2836 lbs. stress along bar $c$.
1·94525 : 5000 :: 1·5557 : 3999 lbs. stress along $d$.

$F_1$ $B_1$ − $F_1$ $C_1$ = $C_1$ $B_1$ = ·75355 − 21255 = ·541; 1·94525 : 5000 :: ·541 : 1391 lbs. load on the joint B.

$F_1$ $C_1$ + $F_1$ $D_1$ = $C_1$ $D_1$ = ·67885; 1·94525 : 5000 :: ·67885 : 1745 lbs. load on the joint C.

$F_1$ $E_1$ − $F_1$ $D_1$ = ·7254; 1·94525 : 5000 :: 7254 : 1864 lbs. load on the joint D.

1·94525 : 5000 :: $F_1$ $E_1$ : 3093 lbs.,

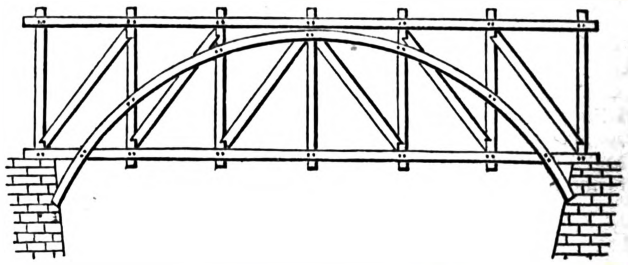
the vertical weight falling on the support at E, the remainder of the weight, or 5000 − 3093 = 1937 lbs., must fall on the support at A. The horizontal stress being represented in the diagram of forces by O $F_1$ = 1, we have 1·94525 : 5000 :: 1 : 2570 lbs., the horizontal stress of the frame. When the load is properly distributed, the necessary stays, C E, A C, require but little strength; without stays such a frame, however well balanced, would be unstable.

*Examples of Bridges in which the actions of combined forces have been applied with more or less success.*—The McCallum Inflexible Arched Truss Bridge approaches nearer the standard of perfection than any other wooden bridge that has fallen under our notice; this fact is easily established by comparison and demonstration.

Fig. 1369 is what is known as the *Burr Bridge*. It is composed of lower and upper chords, and posts and braces. The posts are framed into the chords, and the braces are framed into the posts. Arches are placed on each side of the truss, securely fastened thereto, and, extending below the lower chords, abut against the masonry. This form of truss was extensively used throughout Europe and the United States previous to the introduction of railroads. Many spans were of great length, and in cases where the arches were large, and the masonry sufficiently permanent, this bridge was comparatively successful. Much difficulty was, however, experienced by reason

of the absence of counter-braces. A moving load produced a vibratory and undulating motion, tending to loosen the connection of the timbers, which generally resulted in failure. Many of the *first* railroad bridges, both in Europe and America, were built upon this plan; but much greater difficulty was found in adapting it to the use of railroads than had been previously experienced in its use upon common roads. This difficulty arose from, first, the practical impossibility of perfectly combining the action of the *arch* and the *truss* (each system, of itself, being insufficient to carry the whole load); and, second, the absence of counter-braces. These defects, clearly apparent in their use on common roads, were greatly aggravated under the increased and concentrated nature of the weight, and the rapid transit of trains on railroads. It is true they were obviated in part by adding largely to the amount of material in the structures; but as the difficulty was inherent in the plan, violent contortions in shape could not be prevented, and these in time caused failures. These remarks are intended to apply to spans of considerable length, as experience has proved that plans of even an inferior grade may be measurably successful in spans of ordinary length; whereas nothing short of the most judicious distribution of material will ensure permanency in cases where long spans are indispensable, and any arrangement which can be made permanent in the latter case must certainly prove so in the former. It is worthy of remark here, that this particular combination of the arch with the truss is even now, with some, a favourite idea, but it is believed that its warmest advocates will be generally found among those whose opportunities for practical investigations have been limited, and that it is only necessary that the question be properly presented to them, to produce a change of views in respect to it. This partiality for the combination of the arch and the truss is attributable partly to the fact that the simple truss has in many instances failed, and, as a last resort, the arch has been added, of such dimensions and strength as to be competent to carry the truss and load; the truss serving only as a stiffener to the arch, while the latter, thrusting upon the masonry, has sustained the whole weight. Besides, to the casual observer who has never studied bridge construction, this combination presents at least *an appearance* of great strength and solidity, which do not in fact exist. That the simple truss without the arch has failed in some instances is unquestionably true; but while many of these failures have been caused from inattention to, or ignorance of, the laws regulating the composition and resolution of forces, by far the greater number have arisen from the inferior quality, or lack of the requisite amount of material, or from inferior workmanship. The acknowledged failure of the *Burr Truss*, as applied to railroad purposes, led to the invention of several other plans, all of which were based upon the abandonment of the arch, and were aimed at perfecting a truss, which *of itself* would be sufficient to meet the emergencies of the case. This was in pursuance of what was considered a very reasonable hypothesis, namely, that *one* system properly proportioned must prove much superior to any method or arrangement in which the attempt was made to combine *two* distinct principles, in their nature heterogencous. Among the most prominent plans presented to remedy existing defects was one invented by Stephen H. Long. This plan of bridge was composed of lower and upper chords, posts, and braces, similar in outline and general arrangements to the Burr Truss, but differing from it in detail. An efficient system of counter-braces was introduced; these were made adjustable by wooden wedges, as were also the sustaining braces, by means of which any desirable elevation or deflection might be given to the truss. This plan of truss was rigid to a degree not previously attained; and to such an extent was this true, that, when properly adjusted, no perceptible deflection was produced by the passage of the load. It was, however, found difficult to keep it in adjustment, in consequence of the great shrinkage of the wedges and other timbers of the truss.

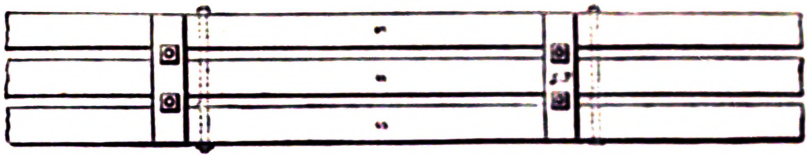
1369.



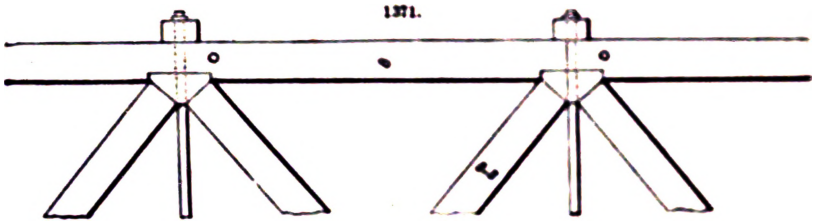
The bridge from which this example, Figs. 1370 to 1373, of Long's framing is taken consists of seven equal openings of 180 ft., measuring from centre to centre of the piers. The bottom string course is a beam built of six planks, each a foot in depth, four of the planks being 5 in. in breadth; and the two outside planks each 4 in. When put together these planks form a beam 12 in. in depth and 28 in. in breadth. The planks are bolted together by screw-bolts, placed about 2 ft. apart and alternately near the top and bottom of the beam, as shown in the vertical section, Fig. 1372. Short wedges of wood are let into the bottom string to the depth of about 1 in., and into the sides of these wedges are mortised the ends of the diagonal braces, Fig. 1371. These diagonal braces abut against similar wedges which are let into the top string beam. The top string consists of three lines of 8 in. square timber, placed with a small space between each, so as to make the whole breadth of the beam 28 in., the same as that of the lower string. The pieces composing this beam are bolted together at intervals of 7 ft. All the braces are 8 in. square, and the number of braces abutting on each block, both at the top and bottom string courses, is always three, arranged two on one side and one on the other. Along the top string beam are fixed short cross pieces, 5 in. by 7 in., one above each of the abutting wedges. These cross pieces receive the tops of the vertical ties, which pass entirely through the framing from top to bottom, and are secured above the top string and below the bottom one by screw-bolts and nuts. Similar cross pieces below the lower string receive the extremities of the vertical ties. Two of these vertical ties pass through each of the abutting wedges, so that for the two sides of the bridge there are four vertical ties in each length of 7 ft. The frames are connected at the top by cross beams, and

the lateral stiffness of the bridge is further increased by wrought-iron ties at each of the piers, these ties being carried into the masonry at some depth below the platform of the roadway. The longitudinal sleepers for the railway, which has only a single track over this bridge, are laid upon transverse beams, which rest upon the bottom string pieces and are placed one on each side of each of the abutting wedges throughout the whole length of the bridge. The platform is further strengthened by diagonal horizontal beams framed between the bottom strings, Fig. 1373.

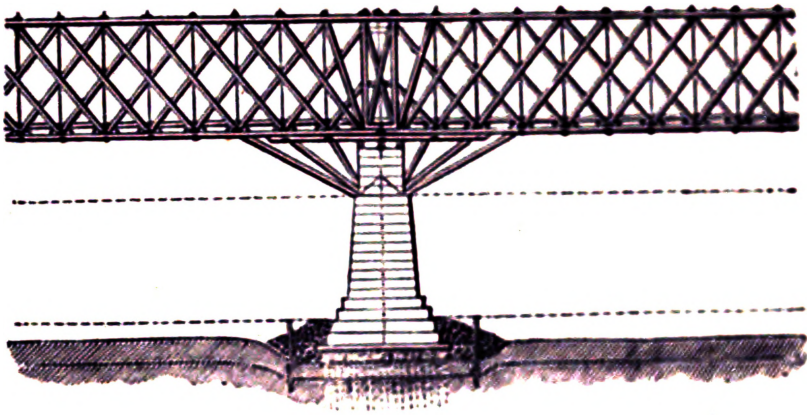
1370



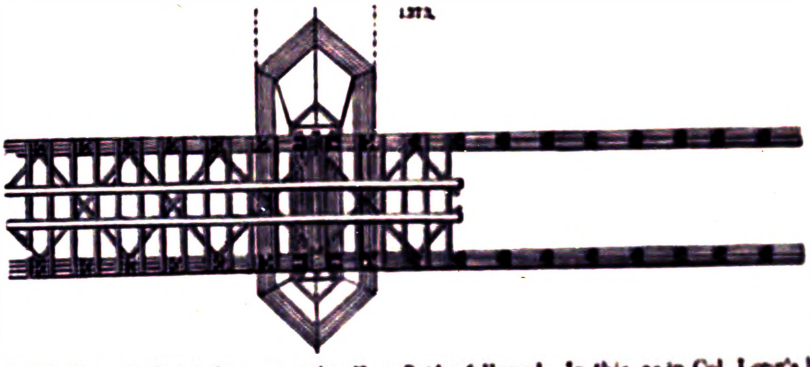
1371.



1372.



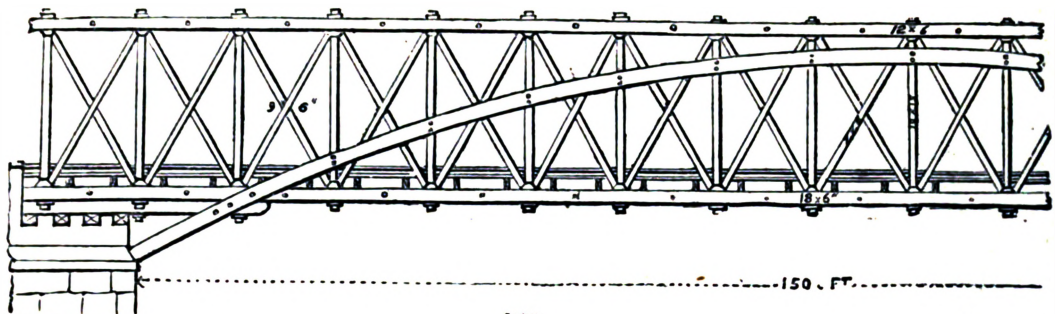
1373.



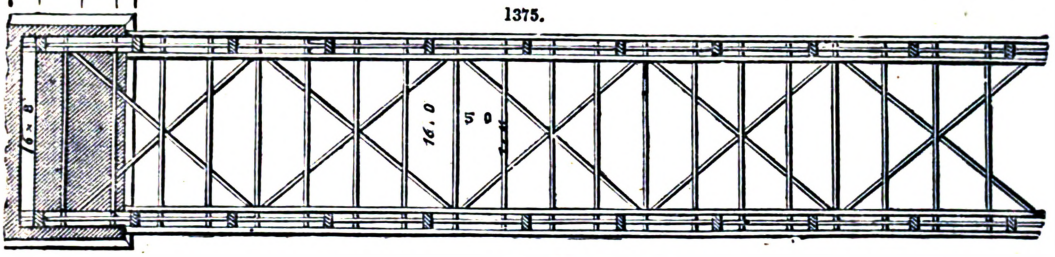
The invention of what is known as the *Howe Bridge* followed. In this, as in Col. Long's bridge, the idea of combining the arch with the truss was originally abandoned for reasons heretofore given, and it was believed that this simple form of truss would prove equal to any reasonable requirement. In the *Howe Bridge*, the posts used in the Burr and Long bridges are dispensed with, and iron rods substituted, by means of which any desirable camber may be given to the truss, thus overcoming the practical difficulty previously experienced in the adjustment of Col. Long's bridge, by the use of wooden wedges. This method of producing camber is certainly an improvement upon the means adopted in the Long Bridge for that purpose, but is much inferior to the latter in its method of counter-bracing, in that they are not adjustable, and perform a *negative* rather than a *positive* duty.

The Improved Burr Truss, introduced by Thomas Steele, is shown in elevation, Fig. 1374; Fig. 1375 is part of the plan of the same; and Figs. 1376, 1377, the detail to a larger scale of the tension-posts, braces, and counter-braces, upper and lower chords, and their iron fastenings.

1374.

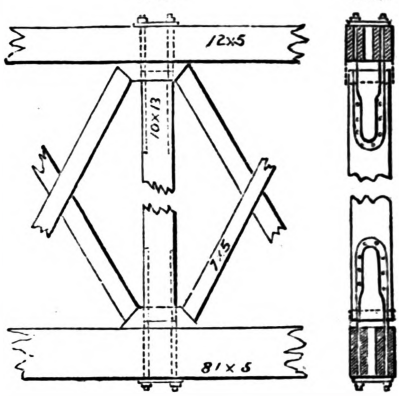



1375.




In this method of combining an arch with a trussed frame the arches are connected with the tension-posts, and the posts with the chords by screw fastenings, as seen in Figs. 1376, 1377; and all is so arranged as to admit of changing the position of the arches relatively to the chords, or of drawing together the chords without changing the position of the arches, and thus regulating and distributing the strain over the different parts of the bridge at pleasure. This adjustment must take place once or twice in each year until the timber becomes perfectly seasoned; after which, in a well-constructed bridge, but little attention will be required. Plates of iron should in all cases be introduced between the abutting surfaces of the top chords and arches, and all possible care taken to prevent two pieces of timber from coming in contact, by which decay is hastened. Care should also be taken to obtain the curve of the parabola for the arches, as it is a curve of equilibrium and of greatest strength.

1376. 1377.




The parabola is the curve of equilibrium when no load is upon the bridge, and also when the load is uniform; but there can be no curve of equilibrium for the variable load of a passing train. Stiffness can be secured in this case only by an efficient system of counter-bracing. The Improved Burr Truss, of Steele, Fig. 1374, presents an example of one of the systems to produce the required stiffness.

Bridges constructed on this plan will be found to possess an unusual amount of strength for the quantity of material contained in them, and, if well built and protected, great durability.

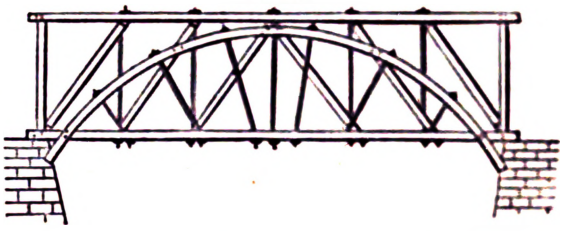
The following are the points to be attended to in erecting one of these bridges, as given by the inventor in Haupt's Treatise on Bridges:—The truss must first be raised, provided with suitable cast-iron skew-backs to receive the braces and tension-posts; and the several parts of the chords should be connected with cast-iron gibs. Wedging under the counter-braces must be avoided by extending the distance between the top skew-backs sufficiently to bring the tension-posts on the radii of the curve of camber of the bridge. The tension-posts must be about 8 in. shorter than the distance between the chords; and in screwing up the truss care must be taken not to bring their ends in contact with the chords; but they must be equidistant, and about 4 in. from them. When the truss is thus finished it must be thrown on its final bearings; and it is then ready to receive the arches which should be constructed on the curve of the parabola, with the ordinates so calculated as to be measured along the central line of the tension-posts. They must be firmly fastened to the posts and bottom chords by means of strong screw-bolts and connecting-plates, as shown at *d d*, and should abut on the masonry some distance below the truss, which can be effected with safety, as the attachment to the posts and chords will relieve the masonry of much of their horizontal thrust. When a bridge thus constructed is put into use, it will be found that, as the timber becomes seasoned, the weight will be gradually thrown upon the arches, which will ultimately bear an undue portion of the load. To avoid this, the camber must be restored and the posts moved up, so as again to divide the strain between the truss and the arches.

The *Howe Bridge* is composed of lower and upper chords, braces, and counter-braces, vertical rods, and cast-iron *bearing-blocks*. The braces abut on the *bearing-blocks*, which pass through the chords in such a manner as to permit the rods to bear directly upon them. Spans of considerable length were built upon this plan, but experience proved that even this truss—like all others—had its limit, beyond which it could not be safely extended.

In the progress of railroad enterprises, in order to save large expenditures of money for masonry, longer spans than had been previously used became desirable, and in certain locations absolutely indispensable; besides this, locomotives were largely increased in weight, to meet the demands of traffic, and furnish a more economical mode of working; and thus arose the necessity for the adoption of some other expedient to meet the increased requirements of bridges. As all had been done by way of improving this truss that mechanical skill could devise, and which an extensive practice had amply afforded, it became evident that some *radical* change must be made in its arrangement, to enable it to meet the exigencies of the case. In this emergency the *arch*, heretofore condemned in the *Burr Truss*, was again resorted to; for it had been proved, from the experience which its use in that truss had afforded, that an *arch* of sufficient size, abutting against permanent masonry, would place the truss in a position of secondary importance.

It will be observed that the arch of the Burr Bridge, Fig. 1369, abuts upon the masonry in precisely the same manner as the arch of what is denominated the *Improved Howe Truss*, Fig. 1378 and the difference between the two consists simply in the mode of connection with the truss, and not in any change of principle or method of action.

1378.



It will be seen that the Burr Arch is securely fastened to the posts and braces of the truss, forming a solid adjustable mass. In Fig. 1378 the arches are not fastened to the braces or rods, but have an independent connection with the lower chord of the truss, by means of rods radiating from the former to the latter. By this method it was supposed that any desirable adjustment could be effected, and that the strain could be put upon either system, or equally upon each.

This new arrangement, although plausible in theory, is found impossible in practice, for the following reasons:—

1st. The rods from the arch to the lower chord are of various lengths, consequently the contractions and expansions must vary proportionately.

2nd. Not a single rod in the arch is of the same length as those in the truss, hence the expansion and contraction of the rods in the truss will vary from that in each, and all the rods connecting the arch with the lower chord.

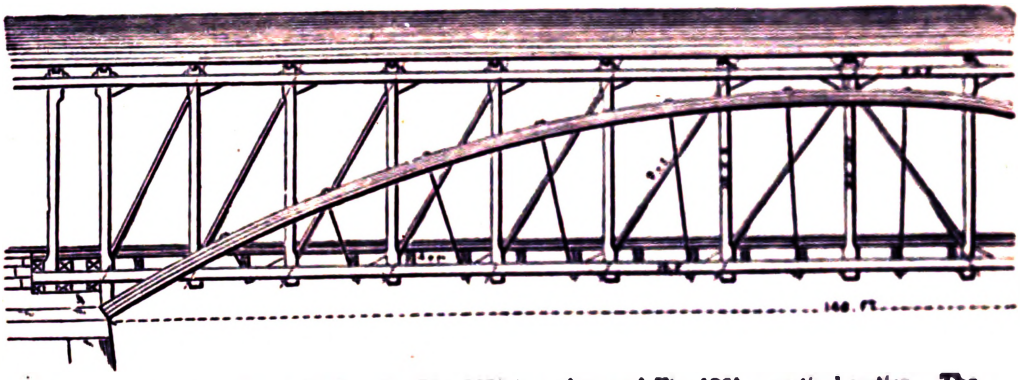
3rd. This combination is exceedingly liable to maltreatment from the careless or ignorant.

4th. And even if it were everything in practice that is claimed for it in theory (which is not the fact), it involves a constant expenditure for adjustment, which must continue during the existence of the bridge itself.

The Burr Truss, Fig. 1369, with all its defects, *can be made superior by far* to the *Improved Howe Truss*, Fig. 1378. For, in the former, there may sometimes be a yielding and compression between the parts of the truss and those of the arch, producing a certain degree of united action; while in the Howe Truss everything depends upon the length of the rods, which must always change with the temperature, and thus render an approach even to perfect adjustment a matter of extreme delicacy. But, in either Fig. 1369 or Fig. 1378, it is clearly evident that, in order to have a structure absolutely safe, the arch and the truss—each of itself, independently of the other—should be of sufficient strength to sustain the whole load, that the strain may be borne alternately by each separate system.

Fig. 1379 shows an elevation of a bridge erected upon Howe's plan over Sherman's Creek, on

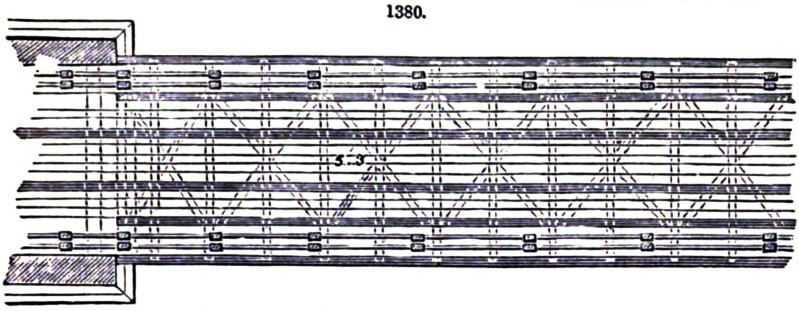
1379.



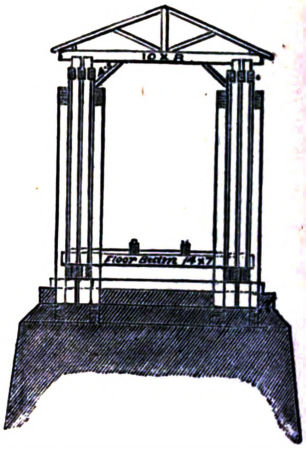

the Pennsylvania Centra. Railroad. Fig. 1380 is a plan, and Fig. 1381 a vertical section. The bridge has two spans, each 148 ft. 3 in. from end to end of the bow, or 154 ft. 6 in. from the

centre of the pier to the end of the truss. The pier is 3 ft. 2 in. wide at top and 6 ft. at the skew-backs. The truss is formed of three rows of top and bottom chords, and two sets of posts

1380.



1381.



and braces. It is counter-braced by rods of 1 in. iron between the braces. The panels increase in width from the end towards the middle of the span. The first panels are 9 ft. 1½ in. from centre to centre of posts, and the middle ones 12 ft. 1½ in.

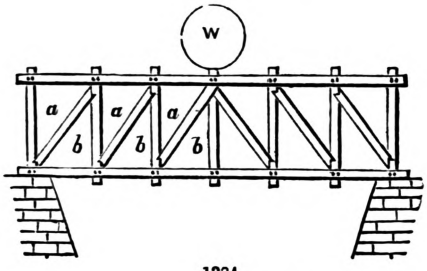
In order to simplify and make clear the real points of difference existing in the combinations of the various plans of trusses of the same general outline, it may be stated that the material composing *any bridge truss*, whether of wood or iron, or of both, is subjected either to *tension or thrust*, and it is upon the proper application of these elements, together with a judicious distribution of the material, rather than upon any difference in detail that the perfection of any bridge structure depends; this may be illustrated by reference to Figs. 1382 to 1385.

Fig. 1382 is the truss of the Burr Bridge; in this the upper chord and braces are acted upon by thrust, and the lower chord and posts by tension.

Fig. 1383 is the Howe Truss, without the counter-braces; in this also the upper chord and braces are subjected to thrust, and the lower chord and vertical rods are acted upon by tension.

Fig. 1384 is a plan of truss sometimes used, the counter-rods being omitted; in this the upper chord and vertical struts are subjected to thrusts, and the lower chords and diagonal rods are acted upon by tension.

1382.

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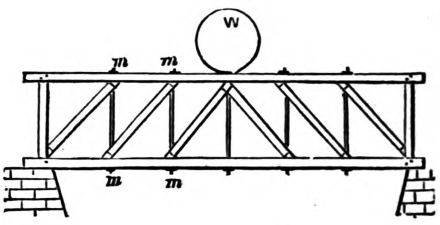


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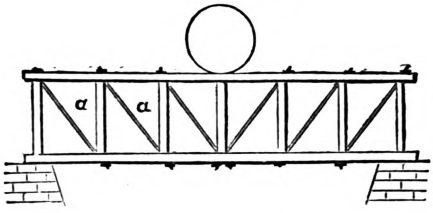


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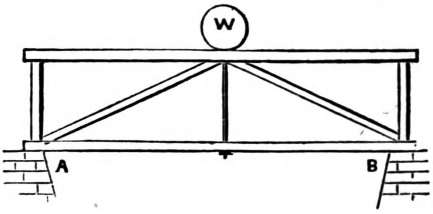



Upon a comparison of these plans it will be discovered that the variations between the Burr Truss, Fig. 1382, and the Howe Truss, Fig. 1383, consist in the use of vertical rods and bearing-blocks in the latter, instead of vertical posts in the former, both having precisely the same duty to perform. It will also be seen that Fig. 1384 varies from Fig. 1383, in that the rods are placed diagonally instead of vertically, changing the element of thrust from the diagonal braces in the latter to the vertical struts in the former, and transferring the element of tension from the vertical to the diagonal line.

Much importance is sometimes attached to just such modifications in detail as exist in Figs. 1382 to 1384, *while the nature and intensity of the destroying forces are the same and equal in each.* This has been proved by actual experiment, by the celebrated engineer and bridge-builder, D. C. McCallum, as follows:—Models were built, one on each plan, of equal length and height of trusses, containing the same sectional area and kind of material in chords and braces, and of equal perfection in details and workmanship, when it was found that the real difference in strength was unappreciable; and it may be well to add, that any given amount placed upon each, in progress of the experiments, presented precisely the same characteristics and contortions in shape, until final failure took place. All bridges having their chords parallel, irrespective of the particular method adopted in combining them, and regardless of the amount of material used in their construction,

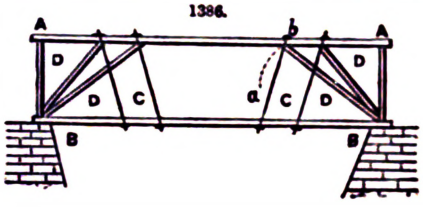
when loaded to nearly the point of fracture, present somewhat the same appearance, the greatest deflection *being invariably* at points near the abutments. This will be understood by the statement, that the vertical strain is increased, as the distance from the centre, to the ends of the truss; at the centre the vertical strain is nothing, and at each end of the truss it is equal to one-half the weight of the structure and its load.

In point of strength, the arrangements, Figs. 1382 to 1384, are not superior to the simple combination, Fig. 1385.

All bridges having their chords parallel exhibit the same uniformity of action, and may be illustrated by reference to Fig. 1386, in which A A is the upper chord; B B, the lower chord; C C, tension-rods; D D, braces.

When a sufficient weight is applied to any truss of this outline, to cause deflection below the straight line, the upper ends of the braces, D D, are made to approach each other, and the distance between the ends is diminished; and as the deflection increases, the upper ends of the braces, D D, will describe arcs, *a b*, of a circle *downwards*, the radius of which being the length of the braces, D D. But when the upper chord is arched, as in Fig. 1387, a sufficient weight will cause the braces, D D, to describe an arc *upwards*, represented by *c d*, Fig. 1387. When the chord, *c e*, becomes straight, the arc will then be described downwards, as shown in Fig. 1386. As an illustration of the McCallum *Inflexible Arched Truss*, see Fig. 1388, in which A A is the lower chord; B B, the upper chord; C C, tension-rods; D D, braces; E E, struts; and W, weight.

1386.

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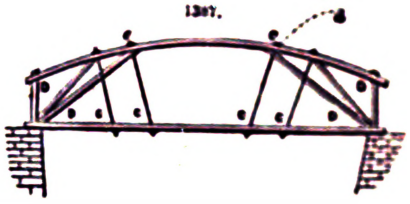


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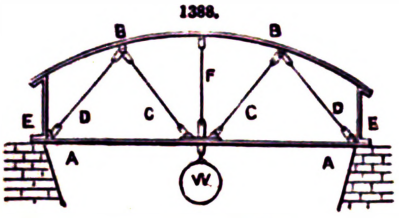


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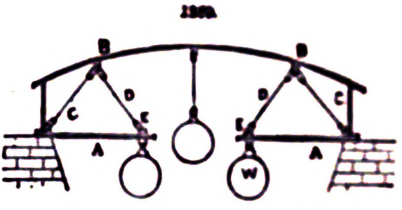



Upon an inspection of this figure, it will be seen that any deflection produced upon the centre of the arch, by means of the weight W, will cause the points B B to separate, by thrusting *outward*, and in the direction of the ends of the truss, producing an *upward* movement of the upper chord, at the ends of the braces D D, the latter describing arcs of a circle *upward*, and from thence will be communicated, by means of the tension-rods C C, to the centre of the lower chord, raising the latter at the point where the rods, C C, meet. By removing the weight W, and inserting a vertical strut at F, the upward movement of the chords will be arrested by the weight W. This peculiar action may be described as follows:—

Any deflection produced in the centre of the arch will cause an *outward* and, consequently, an *upward* force at the upper ends of the braces, which, by means of the tension-rods and strut, is transferred directly back to the under-side of the arch, producing an *upward* force at the latter point, equal to the original *downward* force applied on top of the same. This combination of forces is in agreement with a well-known law, namely, when two forces of equal powers of resistance are opposed to each other, a state of rest is produced.

For a further illustration of the action of this truss, see Fig. 1389, in which A A are pieces of the lower chord, the centre being removed; B B, upper chord, deflected by the weight W. C C are braces which pass through the lower chord and rest upon the masonry. D D are tension-rods. It will be seen that the ends of the pieces of the lower chord at E E are raised considerably above a horizontal line. This upward tendency will continue until the upper chord between B B is deflected below a straight line, when the action will be reversed.

1390.

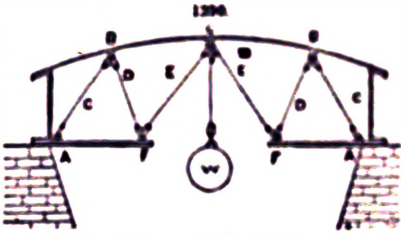
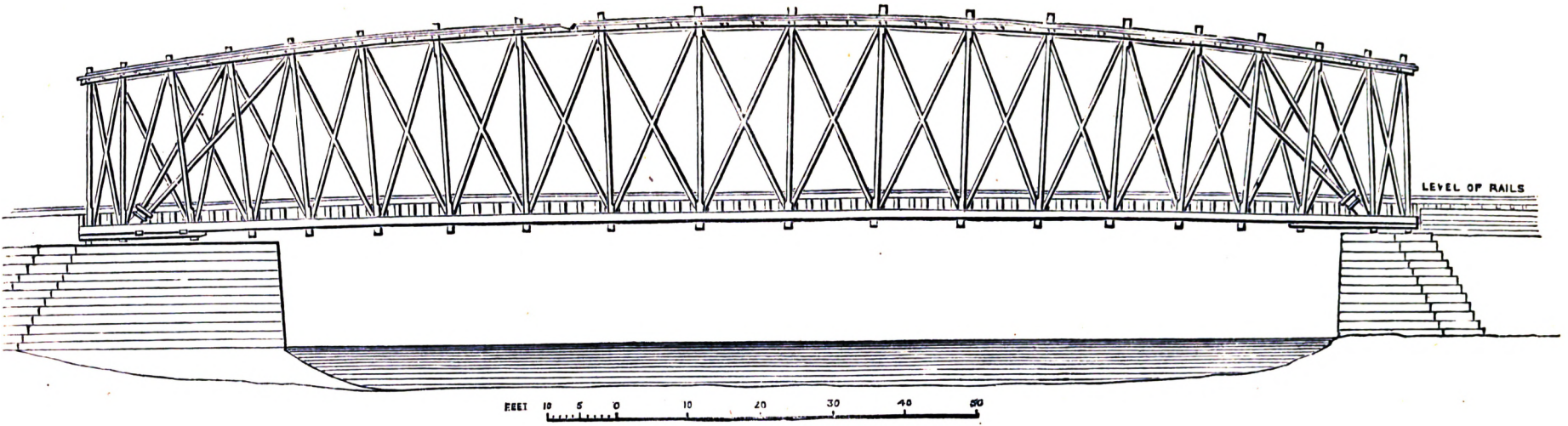



Fig. 1390 exhibits the forces at a state of rest, in which A A are portions of the lower chord; B B, upper chord; C C, arch-braces, which pass through the lower chord, and rest in the masonry; D D, tension-rods; E E, braces; W, weight. It will be seen that the strain produced by the weight W is transferred to the lower chord by means of thrust upon the braces E E, to the points F F, and, by means of tension on the rods D D, to the points B B, and from thence it is brought upon the arch-braces C C, which rest upon the masonry. In this manner a perfect equilibrium of forces is effected, as it is evident that the point G cannot change position, unless the points B B are thrust *outward* towards the ends of the truss, which must raise these points, this being prevented by the strain upon the points F F, communicated by the weight W, through the braces E E.

For a full plan of McCallum's Inflexible Arched Truss the reader is referred to Figs. 1391 to 1395. Upon inspection, it will be observed that the sustaining principle is very much increased

1391.

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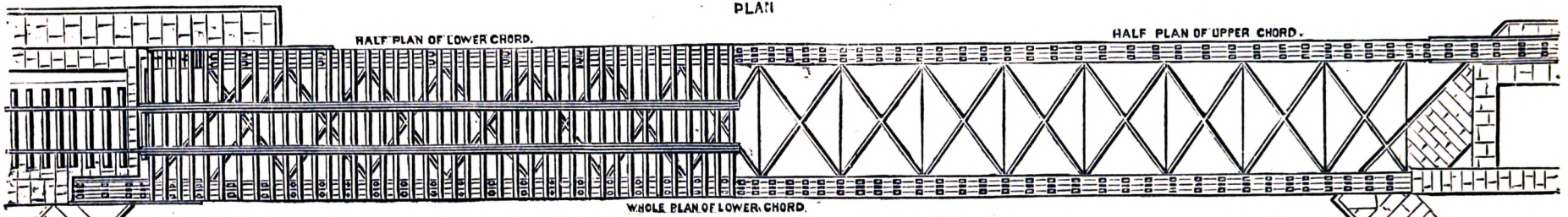


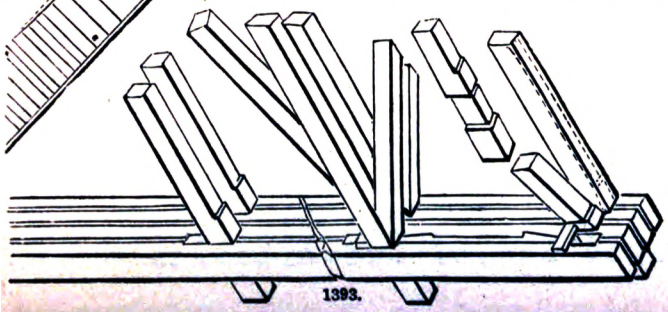

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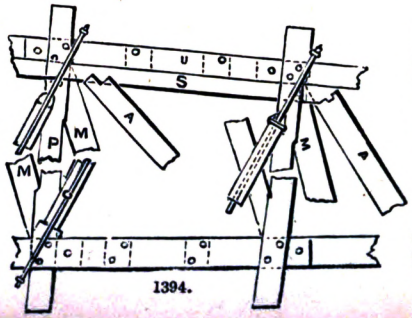


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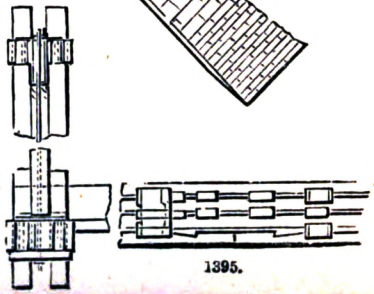


1395.

toward the ends of the truss, not only by the addition to the amount of material at these points, but it will be seen also that the panels become shorter as the vertical strain increases. The posts are placed upon lines radiating with the arch; the braces form equal angles with the posts; and in this way the latter are made to approach more nearly together toward the ends of the truss. The student has already had sufficient evidence of the great strength of this form of truss, and it has also been shown that the tensile strain upon the lower chord is much less than in any other known plan. In fact, the latter may be *entirely severed*, and the structure will still be competent to sustain a heavy load. In this, it differs from all other combinations.

In Fig. 1394, U is the upper chord; S, straining beam; A, arch-brace; M, main-brace; C, counter-brace.

Upon referring to Fig. 1391, which represents a clear span of 180 feet, it will be seen that the arch-braces which rest upon the abutments are extended to points on the arch about 47 ft. from the abutments. From the top of each set of arch-braces, running diagonally on each side of the truss, are placed heavy suspension-rods, which are connected with the lower chords 12 ft. farther from the masonry. Thus the bridge seat is substantially transferred to a point 47 ft. towards the centre of the bridge, reducing a span of 180 to 86 ft., so far as the *tensile strain* upon the lower chord is concerned. For this intermediate space of 86 ft., the arch-beam is of sufficient strength to sustain the whole load, if required. *Strength*, however, is not all that is required, for a railroad bridge especially, subject as it is to a *moving* load; there must also be *rigidity*, *stiffness*, and freedom from vibration. A bridge *may* be strong yet flexible, rigid yet weak; in fact, flexibility is incompatible with durability; the structure should be prepared at all times to receive its load, and should not be permitted to change shape in the slightest degree by its passage over it. To produce this result, an effective system of counter-braces is indispensable.

The proper office of counter-braces is frequently misunderstood, as is evident from the manner of their application in many cases in which they are used as *check-braces only*, having a *negative* rather than a *positive* action; this may be readily shown. When the load is applied, the truss is deflected in consequence of the yielding of the braces; this has the effect of *shortening* the diagonals in the direction of their length, while the diagonals in the direction of the counter-braces are correspondingly *lengthened*; this will leave a space between the ends of the latter, and the *bearing-block* in the lower chord. When the truss is in this condition, if wedges are inserted between the ends of the counter-braces and the lower chord, in such a manner as to fill up the whole space, it is evident that the weight may be removed without at all affecting the shape of the truss, the deflection originally produced by the weight being maintained by the counter-braces, the strain upon the sustaining braces and other portions of the truss remaining precisely the same as when the weight was suspended.

Now suppose the original weight to have been 200 tons, it is evident that, as soon as it is removed, each counter-brace will be subjected to an upward thrust, easily found from its position; the sum of all the thrusts making 200 tons. Now let there be a smaller load applied, this load will not produce any additional strain upon any portion of the truss, nor will the deflection be increased in the slightest degree; the only effect produced by suspending the latter weight will be the relief of the counter-braces, equal to the difference between the first and second weights.

The inventor has found it very difficult to explain this clearly in the course of conversation with some individuals, from the fact that *weight* and *strain* were confounded. Now it is true, when the original weight was applied of 200 tons, the abutments were loaded with just 200 tons more than previously, and the truss was also loaded with 10 tons more; but when the wedges were driven, and the weight removed, while the abutments were relieved of 200 tons pressure, the truss still retained the original strain produced, the weight being required to *produce the strain*, the latter remaining after the former has been removed.

In order to make a practical application of the above, the following method of adjusting the *Inflexible Arched Truss* is submitted. When these bridges are raised, it is usual to load them with a train of locomotive engines, attached closely to each other, and that greater weight may be obtained, the tenders are sometimes detached, and the bridge covered with engines only; with this load, the latter is strained down to a perfect bearing in all its parts; by this means the whole structure is more or less deflected, while the counter-braces are hanging loosely in their places; if, therefore, when the bridge is in this condition with its load, the counter-braces could be lengthened with considerable force, it would not recover its original shape upon removal of the load, but would be held down by the action of the counter-braces to very nearly the same position as when loaded. In this plan of bridge, the lower ends of the counter-braces rest in *iron stirrups*, which are attached to the vertical ties or posts at a point near the lower chord by means of castings and nuts, by which they may be lengthened several inches; in this manner they are made to perform a *positive* duty. When the bridge is adjusted as above, it is clear that a *less* load than that originally applied cannot produce any deflection whatever; the only effect of the passage of a train over it will be to relieve the counter-braces, and will not add a pound pressure upon any timber of the trusses.

In the arrangement of any bridge truss the attainment of the following requisites is desirable:—

1st. Such equilibrium of forces as will produce uniformity of action.

2nd. Such quantity and distribution of material as will ensure *a large surplus* of sustaining principle, *thereby guarding the structure against accident*.

3rd. *Perfect rigidity*, that the combination in all its parts may have permanency *equal to the durability of the material composing the same*.

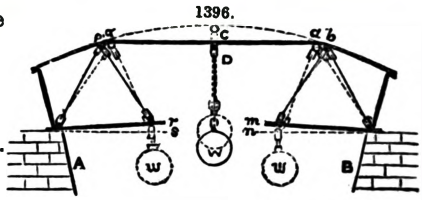
4th. The arrangement of the parts should be such as to be free, if possible, from *the necessity of adjustment*.

The McCallum *Inflexible Arched Truss* meets all these requirements.

*Problem.*—Let it be required to find the equal weights w, w, Fig. 1396, kept in a state of rest by a single weight, W, which has caused the arc $q$ C $a$ to assume the chord $p$ D $b$, the rigidity of

the arc being neglected. Let R = the radius of the arc $q$ C $a$, and put $2c$ = its length; then the chord $q\ a$ and versine C D are readily calculated. Let the chord $q\ a = 2d$, and C D $= 2e$. Let $f$ = A $q$ = A $p$ = B $a$ = B $b$ and $g$ = B $n$ = B $m$ = A $s$ = A $r$. Also let A B $= 2h$

$\frac{2h-2d}{2} = h-d$, $\frac{h-a}{f} = \cos.\ \theta$, putting $\theta$ for the angle $a$ B $n = q$ A $s$.




$\frac{2h-2c}{2} = h-c$, $2h-2c =$ A B $- p\ b$.

$\therefore$ Putting $\phi$ for the angle $b$ B $n = p$ A $s$, $\frac{h-c}{f} = \cos.\ \phi$.

$\therefore\ \phi - \theta =$ angle $a$ B $b = n$ B $m = s$ A $r$.

$\therefore\ m\ n = g \sin.\ (\phi - \theta)$.

Then, according to the principle of work, $2g \sin.\ (\phi-\theta)\ w = 2e$ W. $\therefore\ w = \frac{e\,\mathrm{W}}{g \sin.\ (\phi-\theta)}$.

Let A B $= 2h = 188$ ft.; the length of the arc $q$ C $a$ = the straight line $p$ D $b = 2$ C $= 136$ ft.; R $= 200$ ft.; $m$ B $= g = 60$ ft.; $b$ B $= f = 50$ ft.

It will be found that the arc $q$ C $a$ before being disturbed contains 38° 57′ 40″; the versine of this arc $= 11{\cdot}449$ ft. $= 2e$; the chord $= 133{\cdot}39576$ ft. $= 2d$.

$\frac{h-d}{f} = {\cdot}5460424 = \cos.\ 56°\ 54'\ 15''$; $(\theta)$. $\frac{h-c}{f} = {\cdot}5200000 = \cos.\ 58°\ 40'\ 4''$; $(\phi)$.

$\therefore\ \phi - \theta = 1°\ 45'\ 49''$.

$\therefore\ \frac{e}{g \sin.\ (\phi-\theta)} = \frac{5{\cdot}7245}{60 \sin.\ (1°\ 45'\ 49'')} = 3{\cdot}100092$. $\therefore\ w =$ more than 3 times W.

Consequently, the weight W before reducing the arc $q$ C $a$ to the straight line $p$ D $b$ must raise more than six times its own weight if posited at $s$ and $n$.

*Description of an Iron Bridge, in which the Forces are well combined to meet the demands of Railway Traffic.*—The bridge we now propose to describe is one belonging to a system of bridge-building introduced by Wendel Bollman; it was erected at Harper's Ferry, U.S., the practical working of which was carefully observed by the editor of the present work. This iron suspension trussed bridge was 124 ft. between the abutments. The length of the cast iron in the stretcher was 128 ft. The weight of the cast iron, 65,137 lbs.; weight of wrought iron, 33,527 lbs.; making the total weight of cast and wrought iron, 98,664 lbs.

Fig. 1398 is an elevation of part of the side, showing one pier and part of the cast-iron stretcher. The cap is removed from the pier to show how the rods are secured.

Fig. 1397 is an elevation of both piers and of the eight panels of which the bridge is composed. The system of arranging the braces and connecting-rods is exhibited in this figure.

Fig. 1401 is a cross-section, showing the floor-bracing and the position of the rails. Fig. 1401 also shows, in section, the roof and posts.

Fig. 1400 shows a plan of the flooring of the bridge, the positions of the rails, and floor-bracing.

Fig. 1399 shows two posts, part of the stretcher, and the diagonal rods in one of the panels.

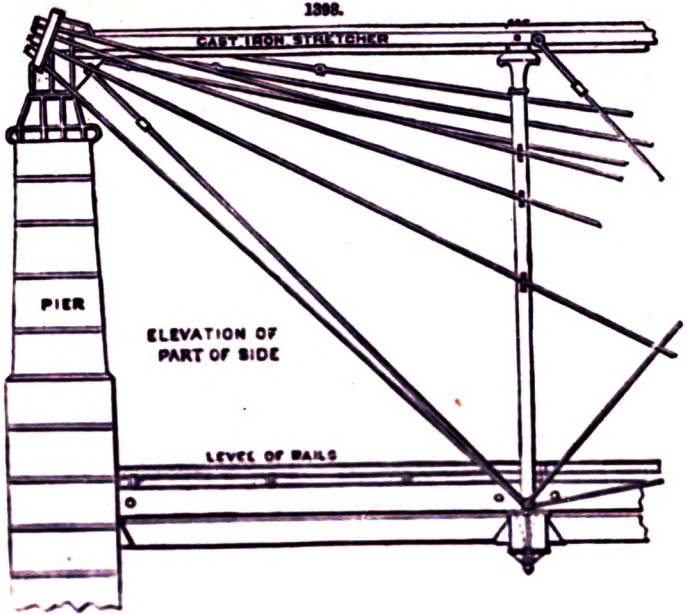
The wrought iron requires little workmanship, the rods from the centre to abutments having but an eye at one and a screw at the other end; with a weld or two between, according to length. The long counter-rods have two knuckles and one swivel for adjustment of strain, and convenience in welding, as well as in raising the whole.

The cast-iron stretcher is octagonal without, circular within, and averages 1 in. of metal. It is cast in lengths according to the length of panel, and jointed in the simplest manner,—at one end of each length is a tenon, at the other a socket. The latter is bored out, and the tenon and its shoulder turned off in a lathe to fit the socket; thus, when thoroughly joined, to form one continuous pipe between abutments. The ends of the sections of cylinders, inserted into those contiguous, are slightly rounded, to allow a small angular movement without risk of joint fracture. A cast-iron plate or washer sets on a bracket cast with each abutment end of stretcher, and at right angles to the centre acting-rods. The tension-bars are passed through this washer to receive a screw-nut for the erection and adjustment of the system. The stretcher or straining beam, the vertical posts, and suspension-bars, compose the essential features of the bridge; each post being hung by two bars from both ends of the stretcher independently of all the others; and each post and pair of tension-bars forming with the stretcher a separate truss. This system, perfect in itself, is additionally connected by diagonal rods in each panel; also by light hollow castings, acting as struts. The diagonal side rods might be safely dispensed with; for the peculiar merit of the truss is its perfect independence of such provision. They are therefore used as a safeguard only in case of the fracture of any of the principal suspension-rods.

By this combination of cast and wrought iron, the former is in a state of compression, the latter in that of tension; the proper condition of the two metals. It unites the principles of the Suspension and of the Truss bridges. *Each* bar performs its own part in supporting the load in proportion to its distance from the abutment; so that the entire series of suspending-rods transmits the same tension to the points of support as would be equally transmitted from thence to the centre of the bridge.

This bridge, it will be seen, is composed of seven independent trusses, which transfer the weight concentrated on each floor beam directly to the abutments, without aid from any other connection; and not from panel to panel, as in general use. The strain on cast and wrought iron is wholly in direct line; and the result, the least quantity of metal is required to carry a given weight. The weight of bridge and load has a vertical pressure on the piers, towers, &c., the only horizontal thrust being from the expansion of iron, which may be accommodated by rollers, sliding on an abutment bracket placed over the pedestal, or by other means: the necessary dimensions of masonry therefore become moderate.

1398.

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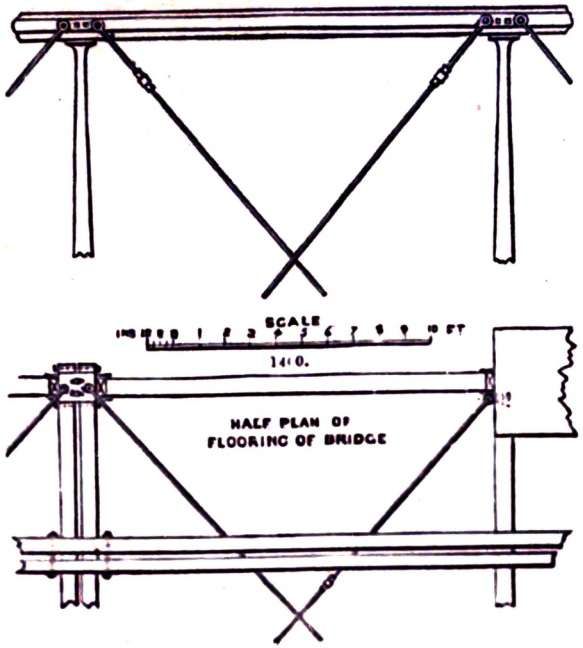


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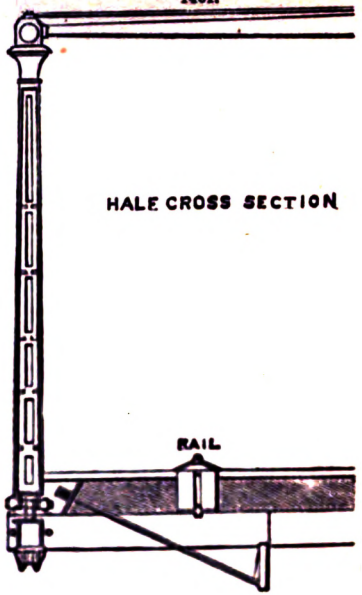


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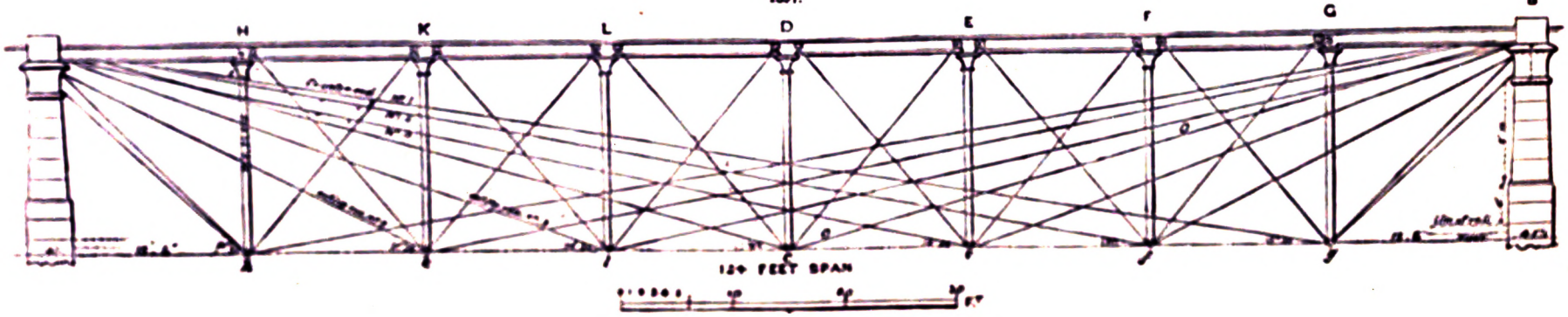


It is evident, from an inspection of the cuts, that no chord is requisite at the bottom of the truss to resist tension; the only advantage of that employed is to regulate the movement produced by expansion, in the performance of which agency the resistance is one to compression. Although the abutment-bracket casting and its pedestal were so constructed as to admit of accommodation to expansion, by rollers, yet such contrivance was omitted with the view of fully testing the effect of greatest expansion throughout the system.

This bridge was inspected by the writer, ten months after it was erected at Harper's Ferry; during which time it had been exposed to extremes of cold and heat, and to an average run of twenty trains daily. From the closest inspection, we find that the extreme expansion measures, as near as possible, $\frac{5}{16}$ in. on each tower, or $\frac{5}{8}$ in. in the entire length, 128 ft. of stretcher; and without the slightest perceptible derangement of masonry; the dimensions of which are 4 ft. square of base, 12 ft. high, and 2 ft. 9 in. at top.

While on the subject of expansion, it may be well to notice the effect from difference in expansion of the rods. At the first point of suspension, or where the longest and shortest rods meet, the counter-rod is about four and a half times longer than the acting-rod; and the expansion of the counter is four and a half times that of the acting-rod. But there is also a proportionate difference in the lengths of stretcher from the point directly over the centre of connection to the extremities of these rods. This has been practically proved in this bridge. The suspender bolt, when the expansion is extreme or $\frac{5}{8}$ in. in length of stretcher, exhibits a motive difference of $\frac{3}{16}$ in. toward the short or acting rod; which difference is provided for, as seen by slot, dotted in elevation, where the vertical suspender bolt moves to accommodate any such difference, and to give that proportion of weight to each rod according to the angle. It affords easy access for repairs; for instance, should a new floor beam be required, it is but needed to slacken the horizontal rod and the keys in longitudinal strut, remove the washer under point of suspension, and let down the beam to be replaced: which can be done without trestling up any part of the bridge. In case of fire, the floor may be entirely consumed without any injury to the side truss.

The permanent principle in bridge-building, sustained throughout this mode of structure, and in which there is such gain in competition with every other, namely, the direct transfer of weight to the abutments, renders the calculation simple, the expense certain, and facilitates the erection of secure, economical, and durable structures.

*Details.*—Resistance of cast-iron stretcher G H to compression, 177,511 lbs., or 4930 lbs. the sq. in. Half weight of bridge and load: weight of iron, 24,000 lbs.; weight of wood, 15,000 lbs.; weight of load, 184,000 lbs.; momentum, 25,000 lbs. = 248,000 lbs.

*Size of Acting-rods.*

No. 1 section of iron $2 \cdot 46 = 2$ bars $1\frac{1}{2} \times \frac{1}{8}$ | No. 3 section of iron $3 \cdot 97 = 2$ bars $2 \times 1$
No. 2 „ „ $3 \cdot 31 = 2$ „ $1\frac{5}{8} \times 1$ | No. 4 „ „ $4 \cdot 31 = 2$ „ $2\frac{1}{8} \times 1$

*Strain on Acting-rods.*

A $h$; No. 1, $\frac{26761 \cdot 8 \times 25}{17} = 39355$ lbs. strain.

A $k$; No. 2, $\frac{23007 \cdot 8 \times 38}{17 \cdot 5} = 49674$ lbs. „

A $l$; No. 3, $\frac{19254 \cdot 1 \times 52}{18} = 55623$ lbs. „

No. 4, $\frac{15500 \times 67}{18 \cdot 5} = 56136$ lbs. „

*Weight on Acting-rods.*

No. 1, $31{,}000 - 4{,}238 \cdot 2 = 26{,}761 \cdot 8$.
„ 2, $31{,}000 - 7{,}992 \cdot 2 = 23{,}007 \cdot 8$.
„ 3, $31{,}000 - 11{,}745 \cdot 9 = 19{,}254 \cdot 1$.

*Value of Iron in Acting-rods.*

No. 1, { 16,000 the sq. in.; 2 rods 7 in. diameter, length 23 ft. 2 in.
{ 2 bars $\frac{7}{8} \times 1\frac{1}{2}$ in. diameter, 25 ft. 3 in. length.
No. 2, 15,000 the sq. in.; 2 bars 7 in. × $1\frac{5}{8}$ in. diameter, 38 ft. length.
No. 3, 14,000 the sq. in.; 2 bars 7 in. × 2 in., length 52 ft. 5 in.

*Size of Counter-rods.*

A $g$; No. 1 section of iron $2 \cdot 5 = 2$ bars $1\frac{5}{8} \times \frac{3}{4}$.
A $f$; No. 2 „ „ $3 \cdot 9 = 2$ „ $2 \times 1$.
A $e$; No. 3 „ „ $4 \cdot 5 = 2$ „ $2\frac{1}{4} \times 1$.

*Strain on Counter-rods.*

No. 1, $\frac{4238 \cdot 2 \times 112}{18 \cdot 5} = 25712$ lbs. strain.

No. 2, $\frac{7992 \cdot 2 \times 97}{18} = 43069$ lbs. „

No. 3, $\frac{11745 \cdot 9 \times 82}{17 \cdot 5} = 55037$ lbs. „

*Weight on Counter-rods.*

No. 1, $\frac{31000 \times 17 \cdot 5}{128} = 4238$ 2.

No. 2, $\frac{31000 \times 33}{128} = 7992$ 2.

No. 3, $\frac{31000 \times 48\ 5}{128} = 11745 \cdot 9$.

*Value of Iron in Counter-rods.*

No. 1, 10,000 the sq. in.; 2 bars 1 × 1¼, length 112 ft. 7 in.
No. 2, 11,000 the sq. in.; 2 bars 1 × 2, " 97 ft. 4 in.
No. 3, 12,000 the sq. in.; 2 bars 1 × 2¼, " 82 ft. 1½ in.

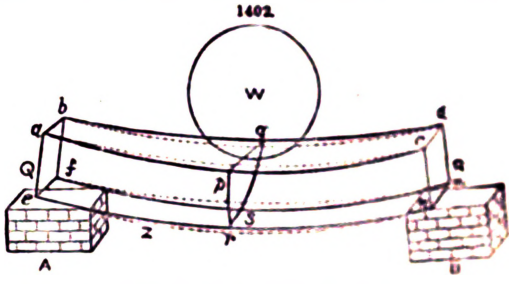
Value of iron in counter-rod *o*, 13,000 the sq. in.; 2 bars 1 × 2½, length 66 ft. 11 in. Length of posts, 15 ft.; diameter of posts, 6 in.; weight on each post, $\frac{248000}{8}$ = 31000 lbs. Diagonal braces, 1 in. diameter, 22 ft. 9 in. in length.

*Trial made on the 1st day of June*, 1852, *to prove the Capability of this Bridge.*—Three first-class tonnage engines, with three tenders, were first carefully weighed, and then run upon the bridge, at the same time nearly covering its whole length, and weighing in the aggregate 273,550 lbs., or $136\frac{1550}{2000}$ tons nett, being over a ton for each foot in length of the bridge. This burden was tried at about eight miles an hour, and the deflections, according to gauges properly set and reliable in their action, were at centre post 1⅜", and at the first post from abutment $\frac{1}{16}$ of an in. From this test it is found that the load did not cover the entire length of bridge by about 13 ft., yet the excess of weight in the middle, and at a speed of about eight miles an hour, produced no greater deflection than 1⅜ of an in. at the centre post, and $\frac{1}{16}$ of an in. at the first point from abutment.

Before proceeding farther, it is necessary to point out some serious mistakes made by experimenters and writers on the strength of materials. When discussing the strength of girders resting on supports, the editor of the present work, in his new theory of the strength of materials, first pointed out fallacies involved through introducing an imaginary line, termed the neutral axis, and merely investigating the upright laminæ of the material. We do not propose to discuss this subject thoroughly here, but to show how errors may be involved when the strength of girders is considered with respect to forces supposed to act only in parallel upright planes. See 'Civil Engineer and Architect's Journal,' June, 1846.

If a beam, Q R, Fig. 1402, rests loosely on two supports, A and B, and is loaded in the middle with a weight, W, which deflects it; before the weight is placed on the beam $a\,b = p\,q = c\,d$; and $e\,f = r\,s = n\,m$; but when the beam is deflected by W, $p\,q$ is greater than $a\,b$ or $c\,d$, and $r\,s$ is less than either $e\,f$ or $m\,n$. Before the beam is loaded it is supposed to be rectangular; in most cases this change of form may be detected by experiment. Although the nature of the material and amount of pressure may render this change of form imperceptible, yet these forces acting across the girder, in the directions of $p\,q\,r\,s$, are in operation, loosening bolts, buckling and puckering upright sheets, and so on. This action should be carefully attended to by engineers in constructing girders, whether solid, hollow, or composed of skeleton frames.

1402.




The material at $r\,s$ is wire-drawn and compressed, while at $p\,q$ the material becomes upset, extended, and loosened, according to the elastic limit and nature of the girder. The current erroneous theory of the strength of materials supposes, when the beam is bent by a weight, W, the fibres are compressed at $p\,q$ and extended at $r\,s$, without alteration of breadth: that is, $p\,q$ remains $= a\,b$ or $c\,d$, and also $= r\,s$ or $e\,f$. A portion of the body will often be forced out near the line $p\,q$; but when the substance supporting the weight is tough, the separation may take place irregularly and diagonally, with a sliding cutting motion, and not directly through the plane $p\,q\,r\,s$, in the middle.

*Stone Bridges.*—The art of constructing stone bridges has always been and still is as much the domain of practice as of theory. The long and intricate calculations which it is necessary to go through in determining the principal dimensions of a stone bridge, though these calculations are always, with a wise precaution, subordinated to practice; the little time which those upon whom the guidance of engineering works devolves have to devote to the calculations, and the dispatch with which projects have to be designed and executed; and other considerations affecting skilful builders who, for want of time or opportunity, have failed to gain sufficient theoretical knowledge, the absence of which might be compensated for by their long practice aided by a few simple and precise principles—all this has induced Edmond Roy, the experienced French engineer, to compress into a few pages some practical information and formulæ, into which enter only the simplest elements of arithmetic and geometry, and by means of which may be readily determined the dimensions of aqueducts, bridges, viaducts, and retaining walls.

Before proceeding farther, we give this practical epitome of Roy: it speaks for itself.

### Empirical Formulæ serving to determine the Principal Dimensions of Bridges in Masonry of Semicircular, Elliptical, Segmental, and Gothic Forms.

*Depth of Masonry at the Crown and Form of the Curve of the Intrados.*—Up to the present time the greater number of empirical formulæ giving the depth of masonry at the crown determine this depth in consideration of the span alone. In this way a bridge having a semicircular or an elliptical arch, even if the latter be depressed to the degree of $\frac{1}{10}$, ought, in accordance with these formulæ, to possess an equal depth at the crown. Such are the formulæ of Perronet, of Gauthey, and of Rondelet.

These formulæ appear to us defective; in proof of which we might point out the great difference

which exists between the dimensions of the masterpieces of the celebrated Perronet and those which they would have had if his formula had been applied.

In determining the thickness at the crown, we ought evidently to take into consideration:—

1. The span of the arch.
2. The degree of depression.

The greatest radius of the curve of the intrados and the magnitude of the arc of the intrados alone corresponding with these two conditions, the depth at the crown in segmental bridges must be determined by the former of these two quantities or by the two combined. It is also obvious that the lateral thrust upon the abutments with the depression given to the arch, and the dimensions of the abutments at the springing, will therefore be determined by the radii of the curves of the intrados. All other dimensions will follow, generally, from the depth at the crown.

*Signification of the Letters employed in the Formulæ.*

Q = the span of the arch.
R = the longest radius serving to determine the depth at the crown.
F = the rise, or distance between the level of the impost and the summit of the intrados.
C = the depth at the crown.

*Semicircular Arches.*

We have $$R = \frac{Q}{2}; \qquad [1]$$

$$F = R = \frac{Q}{2}; \qquad [2]$$

General values .. $$\begin{cases} C = 0{\cdot}30 + 0{\cdot}07\,R; & [3] \\ C = 0{\cdot}30 + 0{\cdot}08. & [4] \end{cases}$$

Formula [3] is applied by us to any span, with ordinary materials.

Formula [4] is applicable to cases in which materials of feeble resistance are employed, such as certain kinds of freestone. The dimensions denoted by this formula are not excessive for spans of less than 12 or 15 mètres, and it may with propriety be employed.

*Arches heavily banked.*—In the case of arches supporting thick masses of embankment, it will be necessary to add to the depth at the crown in the proportion of 0·02 for each mètre of embankment above the extrados.

*Elliptical Arches.*—In the elliptical arch the radius of the upper segment, which is the longest radius, may, in accordance with the various conditions according to which we wish to construct the curve of the arch, have many dimensions for the same span and the same rise. We shall therefore, in order to have a uniform formula for elliptical arches, always consider as a basis of calculation that the curve is of 3 centres only, with segments of 60°. It will not, however, be necessary always to construct the curve of the intrados with 3 centres; it may be of 3, 5, 7, or 9, as may be deemed expedient; we have chosen 3 merely as a uniform basis of calculation. It is plain that a curve of 5, 7, or 9 centres, substituted for one of 3 which has served as a basis of calculation, must have the same rise as the latter. Our opinion is that the curve of 3 centres should never be employed, as it must of necessity be angular.

2. The mode of calculation which we have adopted fixes *a priori* the utmost limit of depression which it is proper to give to elliptical arches, and consequently indicates the moment when we should begin to employ the segment.

The general value of R in cases of curves with 3 centres, the arcs of which are of 60°, is

$$R = Q \times 1{\cdot}183 - 1{\cdot}366\,F. \qquad [5]$$

Let $r$ represent the radius of the lesser arcs, then $r = Q - R$ [6]. If we make $F = 0{\cdot}134 \times Q$ or $\frac{Q}{7{\cdot}46}$, we have $R = Q \times 1{\cdot}183 - 1{\cdot}366 \times 0{\cdot}134 \times Q$; whence $R = Q \times 1$, and

$$r = Q - R = 0.$$

This result agrees with the geometrical principle, that the chord of an arc of 60° is equal to the radius.

Thus, according to our principles, the employment of arches of the elliptical form is limited between $F = \frac{1}{2}\,Q$ and $F = \frac{Q}{7{\cdot}46}$.

On the other hand, if we compare the section of the ellipse, Fig. 1407, which is depressed to $\frac{F}{Q} = 0{\cdot}20$ with the segment of 60° or $0{\cdot}134 \times Q = F$, drawn in a dotted line near it, we shall see that the aperture, or vent, which would result from the employment of each of these two curves would be the same, or nearly so; the difference will be still less on comparing the segment before mentioned with the curve of Fig. 1404. In this latter case it is indeed nothing. Practically, then, there would be no advantage whatever in employing an elliptical arch having a rise of less than $\frac{1}{5}$ of the span, because in such a case we should have a curve too much depressed at the summit, and because this ellipse might be advantageously replaced by a segment with a rise of $\frac{1}{7{\cdot}46}$ affording a vent equal to that of the ellipse.

In practice elliptical arches having a rise of less than $\frac{1}{5}$ of the span have never been employed.

*General Values of the Elements* serving to determine the depth at the crown of elliptical arches:—

$$R = 0 \times 1{\cdot}183 - 1{\cdot}366\,F;$$
$$C = 0{\cdot}30 + 0{\cdot}05\,R. \qquad [7]$$

*Plan of Curves with several Centres.*—Let A B, Fig. 1403, be the span of the arch, and I F the perpendicular on the middle of A B = the rise.

Describe the half-circumference A F' B with ½ A B for a radius.

Divide the half-circumference A F' B into as many equal parts as there are to be centres.

Produce the perpendicular I F as far as F', the point where it cuts the half-circumference and divides the top segment into two equal parts.

Draw the chords B 1, 1 2, 2 F', F' 3, 3 4, 4 A. Take upon A B any two points $r$, at equal distances from the extremities A and B, which will be the centres of the first arc of the curve and the radius of which will be B $r$. Through the point $r$ draw $r o$ parallel to the radius I 1, which will cut the chord B 1 in $o$ and B $o$, and be the chord of the first arc. Through the point $o$ draw $o p$ parallel to the chord 1 2; through the point F draw F $p$ parallel to the chord 2 F': the point of intersection $p$ of the latter two parallels will determine the chord $o p$ of the second arc and the chord $p$ F of the half arc of the summit. Through the point $p$ drawing $p$ R parallel to 1 2, which will cut in $r'$ the radius $o r$ produced, and in R the perpendicular I F produced, the axis of the arch: the points $r'$ and R will be the centres of the second arc and of the arc of the summit. Figs. 1404, 1405, give illustrations of curves with 7 centres. It will be seen that the construction is exactly the same; but the first two radii may be taken at pleasure, and the third, that of the arc of the summit, may be determined as for Fig. 1403, which is the case of a curve with 5 centres only.

It follows from the means which we have pointed out that it would be necessary to proceed cautiously, in order to give the proper dimensions to the smaller radii necessary to produce a regular and graceful curve approaching as near as possible to the ellipse. To avoid this we have drawn up Tables applicable to the describing of curves with 5 and 7 centres, and by means of which we may determine by a simple multiplication the length to be given to the first lesser radii of the curves.

There are only two distinct conditions according to which elliptical curves may be traced:—

1. Supposing that the angles in the centre of each of the arcs are equal to each other.
2. That the magnitudes of the arcs are equal.

We give Tables Nos. I. and II., which satisfy the former condition, and Nos. III. and IV., which satisfy the latter for curves with 5 and 7 centres.

## Elliptical Arches of 5 and 7 Centres, equal Angled.

### No. I.

5 centres, Angles $= \frac{180'}{5} = 36°$.

Proportions:

| Of the Rise $\frac{F}{Q}$ to the Span. | Of the 1st Radius $\frac{or}{Q}$ to the Span. |
|---|---|
| 0·36 | 0·278 |
| 0·35 | 0·265 |
| 0·34 | 0·252 |
| 0·33 | 0·239 |
| 0·32 | 0·225 |
| 0·31 | 0·212 |
| (1) 0·30 | 0·198 |
| 0·29 | 0·185 |
| 0·28 | 0·171 |

### No. II.

7 centres, Angles $= \frac{180'}{7} = 25° 43'$.

Proportions:

| Of the Rise $\frac{F}{Q}$ to the Span. | Of the 1st Radius $\frac{or}{Q}$ to the Span. | Of the 2nd Radius $\frac{pr'}{Q}$ to the Span. |
|---|---|---|
| 0·30 | 0·192 | 0·276 |
| 0·29 | 0·180 | 0·263 |
| 0·28 | 0·168 | 0·249 |
| 0·27 | 0·156 | 0·236 |
| 0·26 | 0·145 | 0·223 |
| 0·25 | 0·133 | 0·210 |
| 0·24 | 0·123 | 0·148 |
| 0·23 | 0·113 | 0·187 |
| 0·22 | 0·104 | 0·177 |
| 0·21 | 0·095 | 0·166 |
| (2) 0·20 | 0·086 | 0·155 |

## Elliptical Arches, with Arcs of nearly equal Magnitudes. 5 Centres.

### No. III.

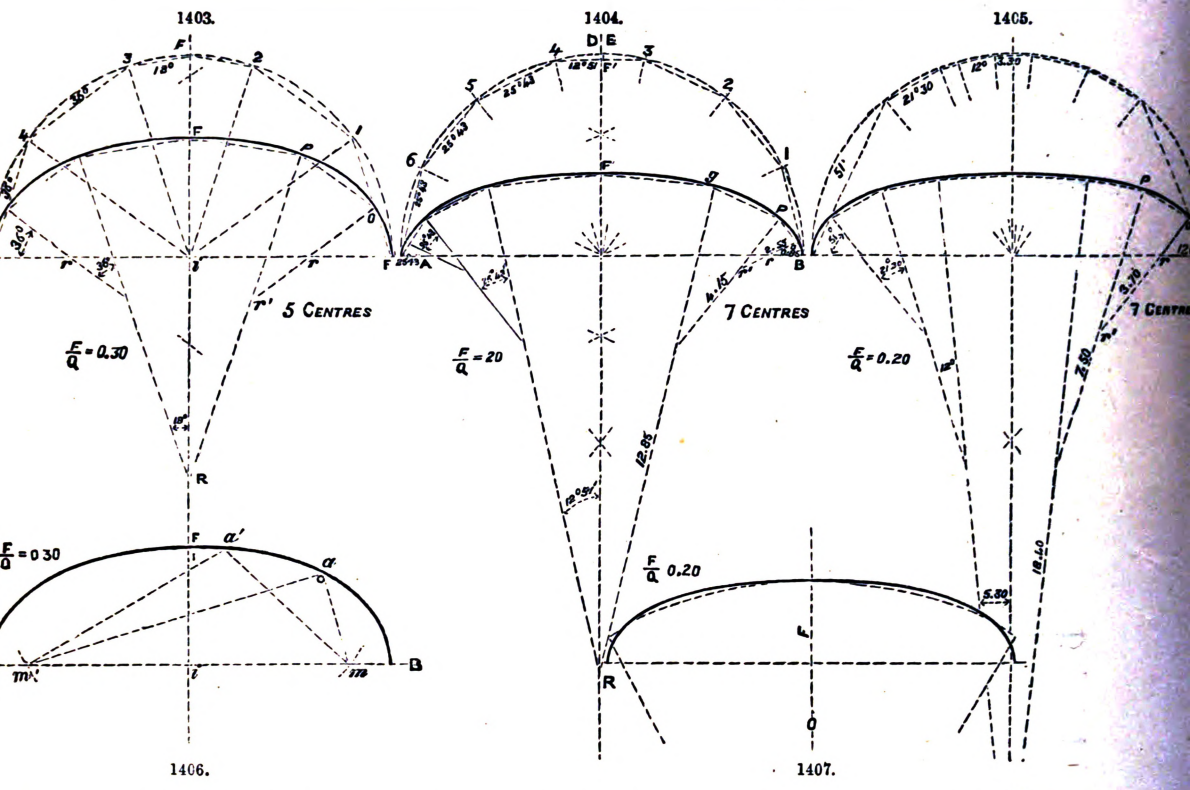
| Proportions: | | Angles: | | |
|---|---|---|---|---|
| Of the Rise $\frac{F}{Q}$ to the Span. | Of the 1st Radius $\frac{or}{Q}$ to the Span. | Of the 1st Radius with the Horizontal Line of the Springing. | Of the 1st Radius with the 2nd. | Of the 2nd Radius with the Vertical. |
| | | ° ′ | ° ′ | ° |
| 0·36 | 0·300 | 49 0 | 32 0 | 9 |
| 0·35 | 0·289 | 50 20 | 30 40 | 9 |
| 0·34 | 0·279 | 51 40 | 29 20 | 9 |
| 0·33 | 0·268 | 53 0 | 28 0 | 9 |
| 0·32 | 0·257 | 54 20 | 26 40 | 9 |
| 0·31 | 0·246 | 55 40 | 25 20 | 9 |
| 0·30 | 0·235 | 57 0 | 24 0 | 9 |
| 0·29 | 0·224 | 58 20 | 23 40 | 9 |
| 0·28 | 0·213 | 59 40 | 22 20 | 9 |

ELLIPTICAL ARCHES WITH ARCS OF NEARLY EQUAL MAGNITUDES. 7 CENTRES.

No. IV.

| PROPORTIONS: | | | ANGLES: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Of the Rise F to the Span Q. | Of the 1st Radius $o\,r$ to the Span Q. | Of the 2nd Radius $p\,r$ to the Span Q. | Of the 1st Radius with the Horizontal Line of the Springing. | | Of the 1st Radius with the 2nd. | | Of the 2nd Radius with the 3rd. | | Of the 3rd Radius with the Vertical. | |
| | | | ° | ′ | ° | ′ | ° | ′ | ° | ′ |
| 0·30 | 0·220 | 0·431 | 44 | 53 | 22 | 37 | 16 | 30 | 6 | 0 |
| 0·29 | 0·210 | 0·425 | 45 | 30 | 22 | 30 | 16 | 0 | 6 | 0 |
| 0·28 | 0·200 | 0·419 | 46 | 7 | 22 | 22 | 15 | 30 | 6 | 0 |
| 0·27 | 0·190 | 0·413 | 46 | 45 | 22 | 15 | 15 | 0 | 6 | 0 |
| 0·26 | 0·180 | 0·406 | 47 | 23 | 22 | 7 | 14 | 30 | 6 | 0 |
| 0·25 | 0·170 | 0·400 | 48 | 0 | 22 | 0 | 14 | 0 | 6 | 0 |
| 0·24 | 0·160 | 0·394 | 48 | 37 | 21 | 53 | 13 | 30 | 6 | 0 |
| 0·23 | 0·150 | 0·388 | 49 | 14 | 21 | 46 | 13 | 0 | 6 | 0 |
| 0·22 | 0·140 | 0·382 | 49 | 51 | 21 | 39 | 12 | 30 | 6 | 0 |
| 0·21 | 0·130 | 0·376 | 50 | 28 | 21 | 32 | 12 | 0 | 6 | 0 |
| (3) 0·20 | 0·120 | 0·370 | 51 | 0 | 21 | 30 | 12 | 0 | 5 | 30 |

NOTE.—The horizontal columns marked by the figures (1), (2), (3), correspond to the examples given in Figs. 1403 to 1405.




The rise and span of an arch being given, divide the rise by the span; the quotient $\frac{F}{Q}$ will be one of the numbers of the first column on the left, or near it: the products of the span by the proportions corresponding to this quotient, situated on the same horizontal line, will give the length of the first radii. The radii near the summit of the curve must be determined from the diagram.

It is necessary to remark that in the application of Tables Nos. III. and IV., in which the angles in the centre are not equal to each other, the divisions of the half-circumference must be made according to the angles indicated in these Tables. See application, Fig. 1405.

The principles of our Tables have nothing absolute about them; they may be varied on the plan and the number of centres increased, if it be found that the limits are too restricted; for the construction employed for 5 and 7 centres is analogous to that to be employed for 9, 11, or 13 centres. Only the flatness of the curve at the summit is proportional to the increase in the number of centres, and greater care is needed in the construction of the plan. Our Tables are designed only to give, within practical limits, the means of avoiding the necessity of making

experiments, and of obtaining *a priori* the required curves. Our general formula [5] gives the values of the radii for a curve of 3 centres with angles in the centres equal.

We do not advise the adoption of the curve of 3 centres for a depression of less than 0·36, for in the two viaducts of Port-de-Piles and of Auzon (railway from Tours to Bordeaux), in the construction of which Roy took part, the former having three arches of 31 mètres, and the latter five arches of 20 mètres. The designs for elliptical arches of 3 centres with angles in the centres equal, gave a depression of 0·33. In the execution of these works, recourse was obliged to be had to curves of 5 centres, because with 3 centres only there was a very distinct angle at each change of curvature.

*Tracing the Ellipsis.*—1. Gardener's ellipsis.

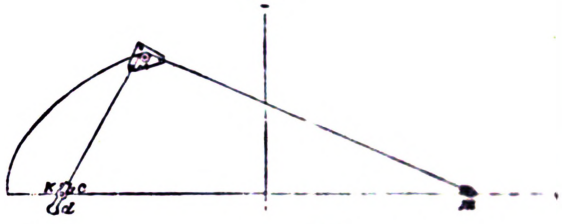
Let A B, Fig. 1406, be the span of the arch and major axis of the ellipsis. Upon the middle of A B raise the perpendicular I F equal to the rise of the arch, which will be half the minor axis of the ellipsis. From the point F, as a centre with ½ A B or I B as a radius, describe an arc cutting the line A B in two points, $m$ and $m'$, which will be the foci of the ellipsis. If at the foci $m$ and $m'$ we fix the ends of a thread, the whole length of which is equal to A B, the major axis of the ellipsis, and with a style keeping the thread equally tense, we move it round from B to F and A, the style will trace a curve which will be an ellipsis, and the right lines $m\,a$, $m'\,a$; and $m\,a'$, $m'\,a'$, drawn from the points $a$ and $a'$ to the foci $m$ and $m'$, are radii vectores, and they show the positions of the thread as the style moves round.

1. The line bisecting the angle formed by the two radii vectores from the same point in the ellipsis is a normal to the curve in this point. This property of the ellipsis will furnish us with a ready means of determining the joints of the voussoirs. We will return to this subject presently.

2. The plan of describing an ellipsis by means of a thread is applicable only to the laying out of gardens, from which its name is derived. For plans of arches where a very exact curve is required, we propose the following method:—

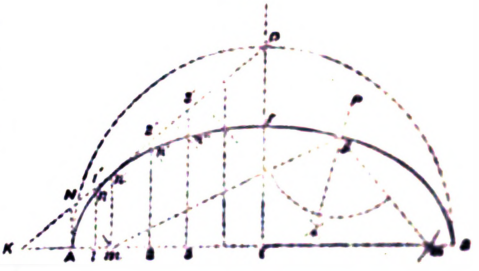
Substitute for the ordinary thread a piece of wire, the diameter of which should be from ¼ to ½ of a millimètre; at the foci $m$ and $m'$, Figs. 1408, 1409, fix two pins, which will serve as points of rotation; one of these pins passes through a hole in the middle of a pair of pincers, closing with a screw, the use of which is to hold firmly one end of the wire; the other pin has a ring attached to it, to which the other end of the wire is fixed. The part $d$ of the pincers is intended to balance the part $c$. Instead of pincers, the part $c$ might have a small cylinder with a ratchet wheel. $m$ is a small flat piece of board, mounted on three rollers turning on their centres; $b$ is a horizontal pulley of 0·05 in. diameter turning on a vertical axis fixed in the board $m$; around this pulley passes the wire which guides the elliptic track that must be followed by the board $m$; through a hole in the board at $q$ passes a style, loaded a little, if necessary, to render its trace upon the plan plainly visible. The board $m$ must always be moved, so that the hole $q$ is on the bisecting line of the angle formed by the radii vectores. The curve thus described will be yet more exact if the pin of the pulley be made hollow to enable the style to pass through it.

1408.



1409.

1410.



*Tracing an Ellipsis through Points.*—Let A B, Fig. 1410, = Q, $i$ the middle of A B, and the perpendicular $i$ F = F. The foci $m$ and $m'$ will be determined in the manner shown, Figs. 1408 to 1410. From the point $i$ as a centre with A $i$ or $\frac{A\,B}{2}$ as a radius, describe the part of the circle A D. At the point A, the extremity of the major axis, erect the perpendicular A N upon A B, equal to A $m'$, the distance from the focus to the extremity of the major axis. Joining the points D and N, the straight line D N produced will meet the major axis A B produced to a point K; the straight line D N possesses properties which form the basis of the method we are about to point out.

1. It will be a tangent to the ellipsis at the point where it is met by a perpendicular to the major axis, erected from the focus $m'$.

2. All the perpendiculars to A B, erected from any points between A and $i$ and included between A B and D N, will be equal to the radius vector passing through the point in which the ellipsis would be met by each of these perpendiculars respectively.

If, then, we take upon A $i$ any points 1, 2, 3, &c., and erect the perpendiculars to A B 1', — 2', — 3', by $m'\,n'$, — 22', — 33', which will meet the straight line D N in the points 1', — 2', — 3', by describing arcs of circles with the focus $m'$ as a centre and radii equal to the perpendiculars 1', — $m'\,n'$, — 22', — 33', between A B and D N, the point in which each of the arcs cuts the perpendicular which has determined its radius will be a point in the ellipsis $a$, $a'$, $a''$, $a'''$.

If we now trace a curve passing through all the points thus obtained, we shall have the quarter of an ellipsis, and the other half of the arch may be formed in the same way.

3. Numerical value of the position of the foci.
We have as the value of the distance from the middle of the major axis to the foci.—

$I\,m' = \sqrt{\frac{Q^2}{4} - F}$, because of the rectangular triangle $m'\,i\,F$.

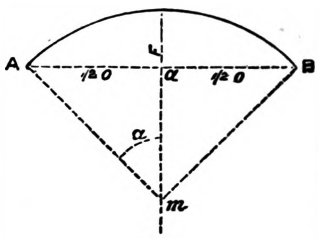
4. Numerical value of the position of the line D K.
We have as the value of the distance from the middle of the major axis to the point K where the line D N meets the major axis $i\,k = \frac{Q^2}{4\sqrt{\frac{Q^2}{4} - F^2}}$, because of the similar triangles D $i$ K and D N $i'$, whence $D\,i = \frac{Q}{2}$.

5. Values of the ordinates of the ellipsis.
The perpendiculars $1\,n$, $-\,m'\,n'$, $-\,2\,n''$, $-\,3\,n'''$, included between the major axis and the curve, are the ordinates of the ellipsis. The parts of the major axis measured from its extremity A : A1, $-$ A $m'$, $-$ A 2, $-$ A 3, are the abscissæ of the above-mentioned ordinates. Representing the abscissæ by $x$ and the ordinates by $y$.

*Section of Elliptical Arches.*—We have $y = \frac{2F}{Q}\sqrt{\frac{Q^2}{4} - x^2}$; the area of an ellipsis being equal to $\pi$, multiplied by the product of the two half-axes, and representing the section of the arch by S, we have $S = \frac{\pi Q F}{4}$.

*Determining the Joints of the Voussoirs.*—When the thickness at the crown and at the springing has been decided upon, the thickness at the springing being greater than that at the crown, it will be necessary to trace the mean ellipsis, having just determined its foci: upon this ellipsis must be marked the divisions of the course of voussoirs. In each of these joints of division will be determined the bisecting line $y\,p$ of the angle formed by the two radii vectores drawn from each point of division, Fig. 1410.

1411.




*Segmental Arches.*—General values of the radius, rise and magnitude.

The chord of an arc or the span of a segmental arch being given, the radius of this arc is determined according to two different conditions, see Fig. 1411.

1. The rise required.
2. The magnitude in degrees and minutes which it is necessary to give to this arc.

The rise being = F, and the magnitude equal A, we shall have for R and F the following values:—

$$R = \frac{F^2 + \frac{Q^2}{4}}{2F}, \qquad [8]$$

$$F = R - \sqrt{R^2 - \frac{Q^2}{4}}; \qquad [9]$$

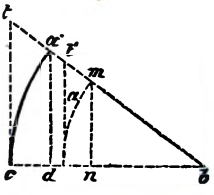
$$R = \frac{Q}{2 \sin. a}; \qquad [10]$$

$$\sin. a = \frac{Q}{2R}; \qquad [11]$$

$$F = R - \cos. a \times R. \qquad [12]$$

*Note on Trigonometry.*—It will be necessary to give a few explanations of the chief terms used in trigonometry, to enable those of our readers who have not studied that science to employ the formulæ we have just adduced. The sine of an angle $a\,b\,c$, Fig. 1412, which we will call $a$ is the perpendicular $m\,n$ let fall upon $c\,b$ from the point $m$, where one of the sides meets an arc described from the summit $b$, as a centre with a radius of 1. The cosine of an angle is the portion of the side $c\,b$ included between the point $n$, the bottom of the perpendicular, and the summit $b$ of the angle, the centre of the arc. The sine of an arc is the perpendicular $a\,d$ let fall from one of the extremities, $a$, of the arc upon the radius $c\,b$, passing through the other extremity, $c$, of the arc. The cosine of an arc is that portion of the radius included between the end of the sinus $d$ and the centre $b$ of the arc. The portion $c\,d$ is called the versed sine, and is equal to the radius $c\,b$ of the arc, minus the cosine $d\,b$. The tangent of an arc, $a\,c$, is the perpendicular $c\,t$ erected from the extremity of one of its extreme radii, $c\,b$, and included between its point of contact, $c$, and the point, $t$, where it is met by the other extreme radius, $a\,b$, produced. The cotangent is the tangent of the complement of the arc.

1412.




*Chief Relations of the Trigonometrical Lines.*—The sinus of an angle or of an arc is equal to the cosinus of its complement. The tangent of an angle or of an arc is equal to the cotangent of its complement, hence the formulæ:—Sin. $a$ = cos. $(90° - a)$; . . . . tang. $a$ = cot. $(90° - a)$.

There are two kinds of tables giving the values of the trigonometrical lines: those giving the logarithms of the values of these lines, and those giving their natural values. Of the former kind are the tables of Callet and De Lalande; of the latter are the tables of Richard, and those contained

in the works of Claudel and Chevallot. All tables are calculated for arcs having a radius of 1. They are usually arranged in the following manner: the number of degrees is marked at the top of the page from 0 to 45°, and at the bottom from 45° to 90°, because, as we have said, the sine, tangent, cotangent, and cosine of an arc are equal respectively to the cosine, cotangent, tangent, and sine of their complement. The number of minutes for angles or arcs from 0 to 45° are found on the left of the page, and for angles or arcs from 45° to 90° the numbers are on the right of the page. The values which are found in the horizontal line of each number of minutes, in tables of log. sines, cosines, &c., are the logarithms of the natural values of the sine, tangent, cotangent, and cosine of the angle or arc whose magnitude is expressed by the number of degrees at the top or bottom of the page, increased by the number of minutes found in the left column for the degrees which are marked at the top, and in the right column for degrees marked at the bottom. All these values, it must be remembered, are calculated for a radius of 1. In tables of log. sines, &c., the index is increased by 10.

From the fact of the values of the trigonometrical lines being given for a radius of 1, it follows from a comparison of the similar triangles $a\ d\ b$ and $m\ a\ b$, that the sine, tangent, cotangent, and cosine of arcs of different radii are to each other as their radii. Thus, when the value of a trigonometrical line has been found in the tables, we have to multiply this value by the radius of the arc in question in order to obtain its true value. The operations on the logarithms of the values of these lines are performed in the same way as on ordinary logarithms, and it will be necessary to remember that the characteristic of all these logarithms (Tables of Hutton) is increased by 10 units, and that the decimal part is always positive.

FORMULÆ GIVING THE DEPTH AT THE CROWN, AND THE PROPORTIONS OF THE RADIUS TO THE RISE, FOR ARCS OF GIVEN MAGNITUDES.

| Elements of the Arch | | | Depth at the Crown = C. |
|---|---|---|---|
| Magnitude. | Radius = R. | Rise = F. | |
| ° | | | |
| 120 | Q × 0·577 | Q × 0·289 | 0·30 + 0·07 R; [13] |
| 90 | Q × 0·707 | Q × 0·207 | 0·30 + 0·05 R; [14] |
| 60 | Q × 1·000 | Q × 0·134 | 0·30 + 0·04 R; [15] |
| 50 | Q × 1·183 | Q × 0·111 | 0·30 + 0·03 R· [16] |
| 40 | Q × 1·462 | Q × 0·092 | 0·30 + 0·02 R; [17] |

*Segments having Magnitudes intermediate to those given in the preceding Table.*—To determine the depth at the crown of segmental arches having magnitudes intermediate to those given in the Table, find the depth with the radius of the arc to be employed for the two magnitudes between which that of the given arc lies; a fourth proportional to the difference of the extreme magnitudes, to the difference of the depths at the crown corresponding to these magnitudes and to the difference between the given and one of the extreme magnitudes, will be the quantity which must be added to or subtracted from the depth at the crown corresponding to the extreme magnitude which has served to determine the fourth term of the proportion.

*Example.*—Let it be required to determine the depth at the crown of a segmental arch of 76° with a radius of 10 mètres.

We shall have for 90° and R = 10ᵐ; C = 0·80
and for .. .. 60° and R = 10ᵐ; C = 0·70

Differences .. .. 30° .. .. 0·10

Therefore $\frac{30°}{0·10} = \frac{90° - 76°}{x}$; whence $x = \frac{0·10 \times 14}{30} = 0·046$.

Hence for 76° and R = 10·00; C = 0·80 − 0·046 = 0·754, this arch would have Q = 12ᵐ·312. F = 2ᵐ·12.

The operation we have indicated will be indispensable only in the case of arcs of magnitudes lying between 120° and 90°, and 90° and 60°, because below 60° the formulæ giving the value of C for variations of 10° and the coefficients of R varying also by 10 thousandths, it will be sufficient to add to the coefficient of the magnitude next smaller, that of the one given, as many thousandths as there are degrees of difference between them.

By performing an analogous operation upon the rise, the calculation of magnitudes may be avoided. The differences obtained will not be exactly the same, but they will be near enough for practice, and the employment of trigonometry may thus be dispensed with.

Referring to the foregoing example, we have: R = 10ᵐ; F = 2ᵐ·12; Q = 12ᵐ·312, whence $\frac{F}{Q} = 0·172$. The proportion of the rise to the span is included between the proportions 0·207 and 0·134 of the formulæ, Nos. 14 and 15. Proceeding in the same way as for magnitudes, we shall have

for $\frac{F}{Q} = 0·207$; R = 10ᵐ; C = 0·80;

$\frac{F}{Q} = 0·134$ R = 10ᵐ; C = 0·70;

Differences .. 0·073 .. .. 0·10

Establishing the proportion $\frac{0{\cdot}073}{0{\cdot}10} = \frac{0{\cdot}207 - 0{\cdot}172}{x}$, we shall have $x = \frac{0{\cdot}10 \times 0{\cdot}35}{0{\cdot}073} = 0{\cdot}048$.

Hence for $\frac{F}{Q} = 0{\cdot}172$ and $R = 10^{m}{\cdot}00$, $C = 0^{m}{\cdot}752$.

Thus this example proves that the radius and the rise of an arch being given, we may determine the depth at the crown easily by the aid of our formula without first considering magnitudes.

*Gothic Arches.*—The best form of Gothic arch is that consisting of two segments of 60°, in which R = Q. It is for this form only that we give a value for the depth at the crown, measured like all the preceding according to the vertical passing through the summit of the arch.

In this case $F = Q \times 0{\cdot}866$; [18]

and $C = 0{\cdot}30 + 0{\cdot}04\,R$. [19]

*Lateral Thrust of Arches.*—The following formula will furnish a means of verifying the depths at the crown, determined according to our formula, and the arrangement of the extrados, which we will discuss later. This formula denoting the horizontal thrust at the key is given regardless of an overweight or an accidental weight.

T = the horizontal thrust for a given length of the arch.
$d$ = the weight per cubic mètre of the masonry.
C = the depth at the crown.
$r$ = the radius of the intrados in semicircular arches; the radius of the curve at the summit in arches with any kind of intrados.

We have $T = \frac{d}{2}(2\,C r + C^2)$. [20]

*Arches of Cellars.*—The depth at the crown of arches for cellars of dwelling-houses will be equal to the half of that of an arch of a bridge, of the same form and the same dimensions (span and rise) $\frac{C}{2}$

*Arches of Buildings.*—The depth at the crown of arches of buildings, such as arches of churches, will be equal to $\frac{1}{3{\cdot}5}$ of that of an arch of a bridge, of the same form and the same dimensions (span and rise) $\frac{C}{3{\cdot}50}$.

### Modification of the Depth at the Crown according to the Nature of the Materials employed, and the greatest Radius of Curvature.

*The Radius of Curvature and the Employment of Material.*—The general formulæ for the depth at the crown given in the preceding chapter were composed on the hypothesis that the employment of materials of various kinds, forming the intrados of arches, would be subject to the dimensions *minima* and *maxima* of the greatest radius of curvature of the arches, and which are shown in the following Table:—

| Nature of the Materials employed. | Maximum Radius R. | Mean Depth. | Pressure on square 0·01 borne by the Masonry: | |
|---|---|---|---|---|
| | | | At the Crown. | At the Base of the Piers. |
| | m. | | k. | k. |
| Rough unhewn stone and concrete .. .. | 2·00 to (3·00) | .. .. | 1·00 | 5·00 |
| Unhewn stone, regular in shape, such as calcareous limestones, laminated trachyte, or rough-hewn stone .. .. .. | 4·00 to (5·00) | 0·25 to 0·30 | 2·50 | 8·00 |
| Stone slightly hewn and bevelled .. .. | 8·00 | 0·33 | 4·00 | 12·00 |
| Hewn or joggled stone and bricks .. .. | 14·00 | 0·40 | 5·50 | 15·00 |
| Cut or free stone .. .. .. .. .. .. | 20·00 | 0·60 | 7·00 | 20·00 |

Above a radius of 20 the mean depth of the cut stone should be increased by 0·03 for each extra mètre of radius.

This Table has been constructed on the supposition that lime only moderately hydraulic will be used. For cases in which lime eminently hydraulic is employed, the values $3^{m}{\cdot}00$ and $5^{m}{\cdot}00$ are given.

The slightly hewn stone, or ashlar, as we understand it, should have its beds bevelled to the extent of 0·12, and the remainder of the bed not too much cut away; the joints should be perpendicular to the facing to the extent of 0·08. Hewn or joggled, stone should have 0·20 of its beds bevelled, the remainder of the bed not too much cut away, and 0·10 of the joints square with the facing. Cut or free stone should have 0·40 of its beds bevelled, and 0·25 of the joints square with the facing. These regulations for the cutting of the stone constitute the utmost allowance which may be made if the work is to be properly executed.

It is easily conceived that if, in the construction of an arch, whose greatest radius of curvature is 14 mètres, in which case we might employ hewn stone having a mean depth of $0^{m}{\cdot}40$, we use cut stone having a mean depth of 0·60, this latter having a larger bed, the pressure will be spread

over a larger surface of stone lying well together and of great resisting power. The masonry of rough stone for filling up the haunches might, in such a case, be reduced in proportion to this spread of the pressure over a wider and well-resisting surface.

*Modification of Depth at the Crown.*—Having regard to the preceding considerations, in order to take into account the various kinds of materials employed, with respect to—1, the radius of curvature to which it is to be applied; 2, the *maxima* to which each of them may be employed according to the resistance it offers, and in accordance with the spirit of the general formula which we have given; we have adopted the following rule for cases in which it is required to substitute for the materials considered in the general formula, as seen in the preceding Table, other materials capable of more or less resistance.

C = depth at the crown according to the general formula.
R = the radius of the intrados serving to determine the depth at the crown.

Let R' = the radius *maxima* for the materials to be substituted for those which might be employed, according to the preceding Table, and C = the depth at the crown, modified by the materials substituted for those considered in the general formula of the Table.

We shall then have

$$C' = \frac{C}{\sqrt{\frac{R'}{R}}}. \qquad [21]$$

*Example* 1.—Let us consider a bridge with an elliptical arch in which R = 8$^m$·00, and in the construction of which slightly hewn stone might be employed. Supposing that it is wished to substitute for it cut stone, we shall have R' = 20·00.

General value: C = 0·30 + 0·05 R = 0·70, whence $C' = \frac{0{\cdot}70}{\sqrt{\frac{20}{8}}} = 0{\cdot}51.$

The Table shows that for a radius of 20$^m$·00 the cut stone should have a mean depth of 0·60; when the result obtained is below this limit the conditions are changed, and this shows that the radius *maxima* for the materials should be less than 20 mètres. We conclude from this that hewn stone should be substituted for cut stone, in order to keep within the limits assigned to each of these kinds of materials; and we shall have on this last hypothesis:—

$$C' = \frac{0{\cdot}70}{\sqrt{\frac{14^m}{8}}} = 0{\cdot}53.$$

*Example* 2.—Let us consider the viaduct of St. Germain, inserted under No. 8 in the Comparative Table.

We have R = 5·00. Being semicircular, C = 0 30 + 0·07 R = 0·65.

In this case, according to the Table, slightly hewn stone should have been used; but unhewn millstone grit was employed, for which the Table gives R' = 2·00;

hence $C' = \frac{0{\cdot}65}{\sqrt{\frac{2}{5}}} = 1{\cdot}02.$

The engineer, M. Flachat, gave 0$^m$·95.

These two examples thus prove that the rule we have established takes into account all the conditions of resistance which result from the employment of different kinds of material.

The first example leads to the following conclusion:—Whenever the thickness at the crown, found for a kind of material that has been substituted for that which, in accordance with the Table, might have been employed, is less than the mean depth of the materials substituted, which depth is fixed in the Table, we ought to consider this substitution as impossible, and, further, to determine the *minimum* thickness at the crown with a kind of material of which the mean depth should not be greater than the thickness found for the crown. By proceeding in this manner, we shall keep within the bounds of safety, and be guided by a spirit of economy, which ought, except in circumstances of an extraordinary nature, to be considered in every undertaking. This minimum thickness being thus determined, it is obvious that it will be always allowable to employ cut for hewn stone, and hewn for slightly hewn stone.

*Power of Resistance.*—It will be advantageous to give the results of experiments made upon various kinds of stone and mortar, in order to obtain a general knowledge of their powers of resistance. It will be necessary, however, to remember that these experiments were made in the laboratory, where time and destructive atmospheric agents could have no effect. All bodies possess more or less elasticity, under the action of compression, or the reverse, their particles approach to or recede from each other; these actions have limits beyond which bodies lose the power of resuming their primitive forms when the pressure is taken off, and other limits beyond which, the force of cohesion being exceeded and overcome, a rupture of the particles takes place: the former is the limit of elasticity, the latter the limit of resistance to a crushing or a tractive power. As compression is, generally speaking, the sole influence to which masonry is subjected, we shall consider its employment only with regard to this. In practice, stone may be considered as incompressible; but when the pressure is exerted to a certain extent the hardest fly to pieces. The softer divide into two pyramids, whose bases are the upper and under surfaces of the stone, and whose summits are situated towards the centre; the side portions are driven outwards in the form of splinters. It has been remarked that stones begin to crack as soon as the pressure exceeds the half of that required to crush them; it is, therefore, at this moment that the cohesion of the particles is destroyed, and it is evident that this is the point which must not be exceeded in the

case of masonry having a weight to support. Even this limit should not be reached if the supports are isolated.

Experiments have shown that the weight which prismatic stones of the same nature will support increases nearly as their density. The weight which stones of the same form and nature will support is proportional to the areas of the transverse sections. The resisting powers of three prisms of the same weight and the same nature, having equal bases, are to each other as the numbers 703, 806, and 917, according as their bases are respectively rectangular, square, or circular; which shows that with an equal section a stone increases its power of resistance in proportion as it assumes the cylindrical form.

Representing the resisting power of the cube by 1, that of the inscribed cylinder will be 0·08; that of the same cylinder, placed upon a sharp edge, 0·32; and that of the inscribed sphere 0·26.

It is easier to crush several stones placed one upon another than a solid block of the same form, the same dimensions, and the same nature. For three cubes placed one upon another, Rondelet discovered that the resistance was reduced about $\frac{2}{3}$, a result which the interposition of mortar diminishes, and which is explained by the want of perfect contact of the surfaces. According to Vicat, a cube of 0·03 loses $\frac{1}{6}$ of its strength when it is formed of eight small cubes, and $\frac{1}{4}$ when it is composed of four equal prisms with fixed joints.

It follows from these facts that, having regard to the imperfections in the execution of work, in practice the permanent weight should not exceed $\frac{1}{10}$ of that necessary to fracture the stone, and that, further, in structures composed of ordinary stone or of small materials the $\frac{1}{15}$ or even the $\frac{1}{20}$ should not be exceeded. In the slightest structures the $\frac{1}{8}$ is not exceeded.

According to Vicat, a piece of masonry, composed of cut stone, will, after five months, support a weight of 209,000 kilogrammes per sq. mètre without any alteration of surface, and an average of 40,000 kilogrammes when constructed of unhewn stone lying well together, with mortar moderately hydraulic. The quality of the mortar employed may increase or diminish the powers of resistance, as is shown in our Table of pressures which the masonry has to support. We give for arches a force of pressure which is about $\frac{1}{4}$ or $\frac{1}{5}$ of that proposed by Vicat, and for perpendicular masonry it is nearly the same.

TABLE OF THE WEIGHT OF A CUBIC MÈTRE OF THE DIFFERENT MATERIALS EMPLOYED IN MASONRY WORKS, WITH THE PRESSURE PER SQUARE CENTIMÈTRE NECESSARY TO CRUSH THEM.

| Nature of the Materials. | Weight of a Cubic Mètre. | Crushing Pressure to the Square Centimètre. |
|---|---|---|
| | kilos. | kilos. |
| Basalt and porphyry | 2900 | 2000 |
| Granite generally | 2710 | 620 |
| Sandstone, hard | 2570 | 890 |
| „ soft | 2490 | 4 |
| Calcareous, chonchyllious and hard | 2500 | 400 |
| „ compact (lithographic, lias) | 2500 | 300 |
| „ oolite (globulous) | 2100 | 110 |
| „ sandy | 2000 | 100 |
| Bricks, well burnt and hard | 1600 | 140 |
| „ ordinary burnt (Belgian) | 2160 | 100 |
| Ordinary plaster, mixed stiff, 30 hours after use | 1570 | 50 |
| „ „ less stiff | .. | 40 |
| Concrete with hydraulic lime, 6 months after use | 1830 | 40 |
| Mortar, hydraulic lime, 15 days after use | .. | 4 |
| „ highly hydraulic lime, 15 days after use | .. | 8 |
| „ Vassy cement, half sand, 15 days after mixing | .. | 150 |
| „ highly hydraulic lime, 14 years after use | .. | 154 |
| „ ordinary hydraulic | .. | 80 |
| „ strong lime | .. | 20 |

See SPECIFIC GRAVITY.

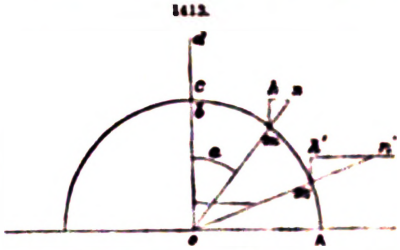
NOTE.—These resistances have been determined by experimenting upon cubes having a dimension of 0·03 to 0·05.

*Plan of the Curves of the Extrados.—Tracing the Curves of the Extrados.*—In arches constructed in one of the usual forms the pressure which acts through the curve of the arch, called the curve of pressure, is the resultant of all the forces acting upon this arch; and it is a principle that this pressure should increase from the crown to the springing. Hence it is necessary, to ensure the stability of the arch, that none of the points of this curve be without the section of the arch; for in such a case the pressure would not be directly supported. From this fact, and from the principle alluded to above, it follows that the thickness of an arch, measured normally at the intrados, which serves as a basis for the form of the curve of pressure, should increase from the crown to the springing.

We admit with M. Dujardin, author of 'Routine des Voûtes,' that an extrados constructed so that *the vertical projection from the part of the radius of curvature of the curve of the intrados, produced to any point between the intrados and the extrados, be always equal to the depth at the crown*, complies sufficiently with the conditions of an increase of pressure, and gives the dimensions of the haunches of an arch in a way to render the disposal of the masonry similar to all points, Fig. 1413.

Let $o$ A = R and $b\,d$ = C. Take any radius, $o\,m$, and at the point $m$ erect a vertical $m\,k = b\,d$ = C; through the point $k$ draw the horizontal, meeting the radius $o\,m$ in the point $n$, to which the latter has been produced; the point $n$ will be a point of the curve of the extrados, and $m\,n$ the thickness of the arch at the haunches. Proceed in a like manner for $m'\,n'$. By joining all the points thus found we shall have the curve of the extrados.

1413.



The numerical value of the thickness of the arch at the haunches will be as follows:—

Representing the angle $b\,o\,m$, formed by the radius drawn to a point $m$, at which point it is required to find the thickness of the arch by $a$; and the thickness of the arch by $e$; we have $b\,d$ = C; and $e = \dfrac{C}{\cos.\ a}$

This method of tracing the curve of the extrados is simple and practical. Figs. 1414 to 1416 are examples of arches of 10 mètres span.

Fig. 1414 is a semicircular arch; Fig. 1415 a segmental arch of 60°; and Fig. 1416 an elliptical arch. The slope of the abutments is in each case $\frac{1}{4}$. In the arch, Fig. 1416, the joint of rupture is determined by $\dfrac{V\,V'}{F} = \dfrac{F}{Q}$. In Fig. 1414 the joint of rupture is at an angle of 60° with the vertical.

*Depths of the Crown.*

| | |
|---|---|
| Semicircular arches .. .. .. .. | C = 0·30 + 0·07 R. |
| Elliptical .. .. .. .. .. | C = 0·30 + 0·05 R. |
| Segmental of 60° .. .. .. .. .. | C = 0·30 + 0·04 R. |
| " of 50° .. .. .. .. .. | C = 0·30 + 0·03 R. |
| " of 40° .. .. .. .. .. | C = 0·30 + 0·02 R. |
| Gothic .. .. .. .. .. .. .. | C = 0·30 + 0 04 R. |

*Values of* R.

| | |
|---|---|
| Semicircular arches .. .. | $R = \dfrac{Q}{2}$. |
| Elliptical .. .. .. .. | R = Q × 1·183 − 1·366 F. |
| Segmental .. .. .. .. | $R = \dfrac{F^2 + \frac{1}{4}Q^2}{2F}$. or $R = \dfrac{\frac{1}{4}Q}{\sin.\ a}$. |
| Gothic .. .. .. .. .. | R = Q. |

*Thickness of the Abutments at the Springings.*

| | |
|---|---|
| In all cases .. .. .. .. | E = 0·20 + 0·30 (R + 2 C). |
| Gothic .. .. .. .. .. | E = 0·20 + 0·15 (R + 2 C). |

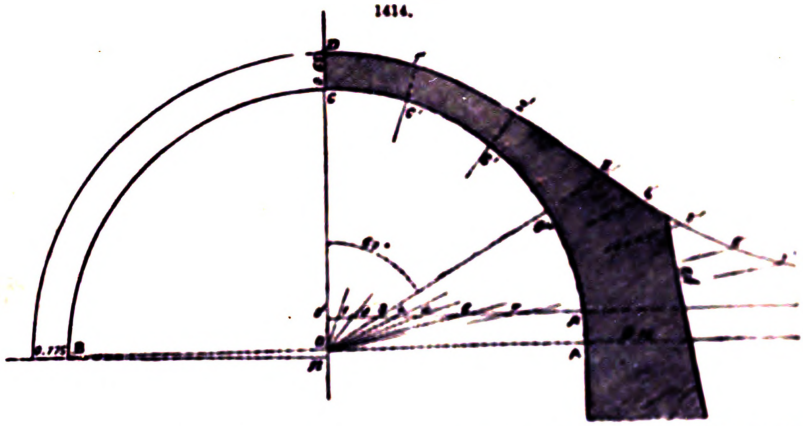
*Thickness of the Piers at the Springings.*

| | |
|---|---|
| With 1 to 8m span .. .. .. .. .. | P = 2·50 × C. |
| 8m and over .. .. .. .. | P = 3 × C. |

*Strengthening of the Head-bands at the Springings.*

$\frac{1}{4}$ Q × 0·025.

1414.



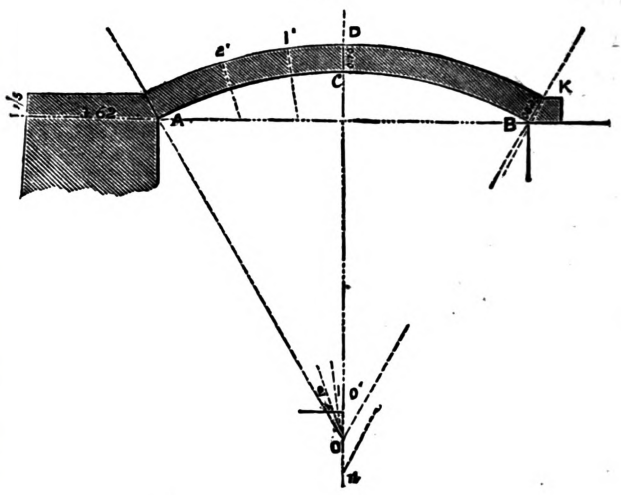
*Example* 1.—Application of the method to a semicircular arch: A B = Q; C D = C, Fig. 1414. Upon $o\,c$ perpendicular to the line of the springing A B, erect from the centre $o$ of the curve of the intrados, a line $o\,o'$ = C D = C the depth at the crown; and remark that $o'$ D = $o$C = R, from

the point $o'$ draw $o'$ A' parallel to the line of the springing. Producing the radii $o\,c'$, $o\,c''$, $o\,c'''$, and so on; these radii will cut the line $o'$ A' in the points 1', 2', 3', and so on; if we now continue these radii from the points 1, 2, 3, and so on, where each of them cuts the line A B to the points 1', 2', 3', 4', 5', 6', 7', making them equal to $o'$ D and equal also to the radius of the curve of the intrados, we shall obtain a series of points D, 1', 2', 3', 4', 5', 6', 7', which will determine the curve of the extrados.

Remarking that each of the portions 0 1, 0 2, 0 3, and so on, is equal to $c'$ 1', $c''$ 2'', $c'''$ 3''', and that $o\,o' = C$ is the vertical projection from the portions of the radii 0 1, 0 2, 0 3, we see that this construction exactly fulfils the conditions already mentioned; that the vertical projection from a part of the radius of curvature of the curve of an arch produced to any point within the intrados and the extrados is always equal to the depth at the crown.

We would remark that the curve in question will never descend (in semicircular and elliptical bridges) to the level of the springing; for this curve which is determined by the sliding of the extremity $o'$ of a line $o'$ D along a line $o'$ A', parallel to that of the springing and distant from this latter by a quantity equal to the depth at the crown, the direction of which in this sliding motion is compelled to pass constantly through the point $o$, the centre of the curve of the intrados, this curve is a conchoid of which $o'$ A' is the asymptote. The point of the curve of the extrados nearest the plane of the springing will therefore be measured by infinity, and its distance from this plane would then be equal to the depth at the crown.

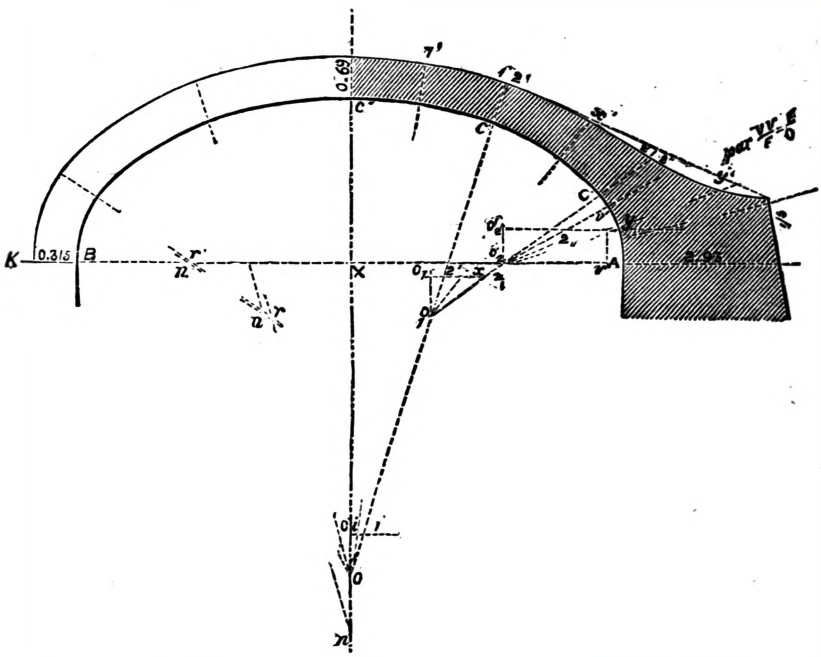
1415.




*Example* 2.—For the segment we have proceeded in the same way as for the semicircle; the determining of the curve of the extrados stopping with the last radius $o$ A, Fig. 1415, it follows that the abutment rises above the plane of the springing by a quantity equal to the depth at the crown. In practice the extrados of the arch must be made to coincide with the top of the abutment according to the dotted line.

*Example* 3.—For the elliptical arch with five centres, Fig. 1416, we have proceeded for each arc of the ellipse in the same way as for

1416.




the half-circumference of the semicircular. Above each of the centres $o$, $o$, $o$, at a distance from these centres equal to the depth at the crown, draw a horizontal, then at each extreme radius of the arcs of the intrados find the points $1'-2'-x'-y$ by the aid of the portions of the radii of curvature $11' = o\,c$, $22' = o_1\,c'$, $x\,x = 22'$, $y\,y' = o'_2$ A.

For all elliptical arches, determine by the aid of a diagram the curve with 5 or 7 centres approaching as near as possible the given ellipsis of the intrados, and deduce from it the curve of the extrados as in the third example. In practice the extrados must be made to coincide with the abutment as shown by the dotted line.

*Abutments and Piers.—Thickness of the Abutments at the Plane of the Springing.*—Let E = the thickness of the abutments at the plane of the springing for arches of all forms, and H = the height of the abutments or piers. We have already R = the radius of the intrados serving to determine the depth at the crown, and C = the depth at the crown.

For any span and any form of arch we shall have

$$E = 0{\cdot}20 + 0{\cdot}30\,(R + 2C); \qquad [22]$$

except for the Gothic arch of two segments of 60, when

$$E = 0{\cdot}20 + 0{\cdot}30\left(\frac{R}{2} + 0{\cdot}2\,C\right).$$

The height of the abutments should not exceed

$$H = Q \times 1{\cdot}50. \qquad [23]$$

Except in cases of absolute necessity, the height should never exceed

$$H = Q \times 2. \qquad [24]$$

The first value of H will give to bridges of one arch the most solid appearance, a quality which public works ought to possess; it is also the limit of the conditions of great stability. The second value of H corresponds to the architectural proportions of a portico; it is also suited to large viaducts.

*Facing of the Abutments on the Land Side.*—The thickness of the abutments at the plane of the springing having been determined by formula [22], the exterior facing (the land sides) will be constructed with a talus of $\frac{1}{5}$ or 0·20 the metre of height. The thickness of the abutments at the base will, therefore, be

$$= E + 0{\cdot}20\,H. \qquad [25]$$

This talus nearly corresponds with the retreats which many builders give to their works; this method, we think, ought to be abandoned on the ground of producing results opposed to those to obtain which it is adopted; namely, greater stability than with the talus. Each retreat is a reservoir of water furnishing a means of enabling it to penetrate the masonry.

In the case of the talus or slope we have taken the mean of the thicknesses at the springing and at the base. This mean may be taken in practice as the uniform thickness of the abutment, the value of which will be

$$E' = E + H \times 0{\cdot}10. \qquad [26]$$

In this case the exterior facing will be vertical. This arrangement will have the following inconvenience:—The pressure supported by the masonry on the level of the foundations will be much greater than that supported at the springing, a fact which might in certain soils be of grave consequences. Besides this, such an arrangement does not correspond in direction of resistance to the pressure of the arch.

The thickness of the abutments thus found needs no assistance of walls, which, if used, will be additional guarantees of stability. When massive walls are placed behind the abutments, if the sum of the mean thicknesses of these two walls be equal to half the width of the work between the headings, openings in the form of arches may be made in the abutments without endangering the solidity of the work. In this way a considerable saving may be effected.

It will not be prudent, however, to hollow the abutment between the walls throughout the whole of its height, for there should always be at the springing a mass of masonry of a width equal to that prescribed by the formula, to provide against the settling down of the masonry at the head and flanks of the arch in consequence of the slipping to which the latter is liable when there is not sufficient surface to resist the pressure.

*Thickness of the Piers at the Springing.*—Let P = the thickness of the piers at the springing, and F = the talus of the piers per metre of height. For a span of 1·00 to 8 or 10·00 we shall have

$$P = C \times 2{\cdot}50, \qquad [27]$$

twice and a half the thickness at the crown.

For a span above $10^{m}{\cdot}00$ we have

$$P = C \times 3, \qquad [28]$$

three times the thickness at the crown.

Talus of the piers a metre of height in all cases

$$\frac{1}{40} \text{ or } F = 0{\cdot}025. \qquad [29]$$

The body of the piers will thus increase to a metre of height by $\frac{1}{40}$ or 0·05.

Besides this, it is well to give as much projection as possible to the socles in order to spread the pressure over a wider surface of natural ground. The nature of the soil, the importance of the work, the flow of the water, and the form of the foundation must guide the builder in the construction of the basis. His duty is to see that the works be firmly placed and protected from the undermining action of the water.

*General Information.*—According to statements made by Rondelet, in his 'Art de Bâtir,' we find:—

That thickness of the piers of a semicircular arch being = 1, the thickness of the piers for one and the same span will be, for—

| | | | |
|---|---|---|---|
| Gothic arch of two segments of 60° | = 0·70 | Elliptical depressed to $\frac{1}{3}$ | = 1·35 |
| Semicircular | = 1·00 | " to $\frac{1}{5}$ | = 1·40 |
| Elliptical depressed to $\frac{1}{2}$ | = 1·18 | Flat-band | = 1·60 |

That representing the thrust of a semicircular arch by 1, the relative thrust of other arches will be—

| | | | |
|---|---|---|---|
| Gothic of two segments of 60° | .. = 0·50 | Elliptical depressed to $\frac{1}{8}$ | .. .. = 1·93 |
| Semicircular .. .. .. .. | .. = 1·00 | „ „ to $\frac{1}{10}$ | .. .. = 1·91 |
| Elliptical depressed to $\frac{1}{3}$ .. .. | .. = 1·40 | Plat-band .. .. .. .. .. | .. .. = 1·95 |

*Position of the Joints of Rupture.*—It follows from the facts which we have gathered from various works, that the position of the joints of rupture in bridges of the semicircular and elliptical forms may be determined in a general manner by the intersection of a parallel at the level of the springing, with the curve of the intrados and the distance of which from the level of the springing is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$ of the rise according as the rise itself is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$ of the span. Calling V V′ this vertical distance, we have the proportion:—

$$\frac{V V'}{F} = \frac{F}{Q}, \text{ whence } V V' = \frac{F^2}{Q}. \qquad [30]$$

This formula is strictly in accordance with the position of the joint of rupture in semicircular bridges, which is always considered as being on the radius inclined to 30° with the horizontal. In segmental bridges, so long as their magnitude is less than 120°, the joint of rupture is at the springing of the arch.

*Proportions of the various Parts.—Head-bands of Arches.*—These should have a greater thickness at the springing than at the crown. This arrangement, which is more rational than one of uniformity, gives the work a certain stamp of solidity; this kind of band is called strengthened.

In arches of moderate span, the thickness of the band at the crown is made equal to the body of the arch = C.

The thickness at the level of the springing being represented for all forms of arches by B, we shall have

$$B = C + \frac{Q}{2} \times 0{\cdot}025; \qquad [31]$$

$$\text{or } B = C + \frac{Q}{80}.$$

For a span not exceeding 4·00 the band may be parallel; for in such a case the increase would be hardly apparent, and it seems to us useless to introduce such a condition into small works.

In arches of a wide span, 20 or 30 mètres, the thickness of the head-band is often made less than that of the body of the arch. This reduction varies from 0·10 to 0·20, according to the hardness of the materials or the taste of the builder. While giving the work a bolder appearance, this reduction in no way compromises its solidity. It is besides quite in harmony with the principles which we have made known.

*Tracing the Exterior Curve of the Head-band.*—In semicircular arches the extrados will be determined by a segment, the centre of which will be below that of the intrados by $\frac{Q}{2} \times 0{\cdot}025$, and the radius of this arc will then be equal to $R + C + \frac{Q}{80}$.

In elliptical bridges, first determine the value of B, then divide the increase of the thickness of the band, or the difference between the thicknesses at the crown and at the springing, by the length of the half of the curve of the intrados (measured simply with the compasses); this will give the increase of the band for each mètre of length. Multiplying this quantity by the length, 1, of the half-arc of the summit, 2, of each of the other arcs of the ellipse, we shall have the thickness of the band at each change of curvature. The arc of the summit will be determined by three points, and will have its centre at *n*; the centre of the second arc will be found upon the last radius passing through *n*. It is besides determined in position by its two extremities, and its centre will then be at *n′*; in the same way we shall have the centre *n″*, Fig. 1416.

For elliptical arches we may also trace the ellipse of the extrados, the major and minor axes of which will be determined by:—The major axis = Q + 2 B, and half the minor axis = F + C.

In these kinds of arches the joints of the voussoirs should be traced according to the normals at the mean curve of the head-band, and not according to the normals at the intrados; by this means the pressure is distributed more equally on the planes of the joints. This arrangement corresponds in some degree to the inclining of the planes of the joints recommended in the learned work of Yvon-Villarceau on 'The Construction of the Arches of Bridges considered with regard to their Stability.'

For segmental bridges the extrados will be a segment having three points, the crown and the springings: its centre will be in *n*, Fig. 1415.

*The Voussoirs.*—The key voussoir ought always to be a header; and, as far as possible, the springers should be the same. Now the key is always like the first voussoir when the half of the total number of voussoirs of one head minus one is an even number. We are thus able to fix *a priori* the number of voussoirs to be put into an arch, and the builder will be guided by this in regulating the piers and abutments.

*Plinths and Cordons.*—Let the total height of the structure from the top of the foundations to the bottom of the plinths = H, the height of the plinth = *h*, and the ledge of the plinth = *s*, then in all cases

$$s = 0{\cdot}20 + 0{\cdot}02\,H. \qquad [32]$$

For plinths without mouldings for small structures, $s = \frac{1}{2}h$;

„ plinths with mouldings .. .. .. .. .. $s = 0{\cdot}70\,h$. [33]

When it is required to gain width and to place the parapet beyond the masonry, it will be necessary to put a console under the plinth, the height of which console will be 0·70 h. We have P = the thickness of the piers.

Representing the height of the cordon also by h, we shall have

$$h = \frac{P}{7}. \qquad [34]$$

However, in cases in which the height of the cordon thus formed would exceed that of the plinth, it will be necessary to reduce it and to make it equal to this latter.

For details of mouldings, see Figs. 1417 to 1423.

*Details.—Piers* :—Thickness of the piers at the plane of springing :—

1st, up to 10 mètres span .. .. .. .. P = 2·50 × C.
2nd, under 10 mètres span .. .. .. .. P = 3 × C.

Slope to a mètre in height, 0·025, or $\frac{1}{40}$.

*Plinths and Cordons* :—

Total height from the top of the foundations to the under-side of the plinth = H.
Total thickness of the plinth .. .. .. .. .. .. .. .. .. .. = h.

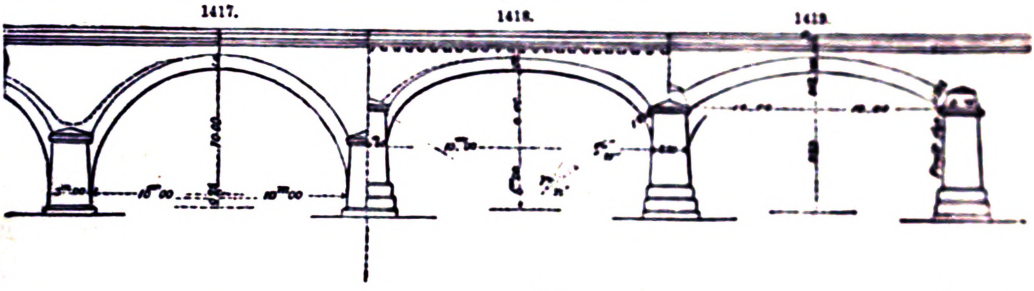
We shall have h = 0·20 + 0·002 × H.

Ledge of the plinth { Small works .. .. .. 0·50 × h.
Large works .. .. .. 0·70 × h.

Total height of the cordons h' = ½ of the thickness of the piers. If this thickness exceeds that of the plinth, reduce h' = h.

The designs of cordon and plinth, Figs. 1417 to 1423, are specimens in which all the dimensions of ledges, plat-bands, and fillets are given, supposing the height h to be unity.

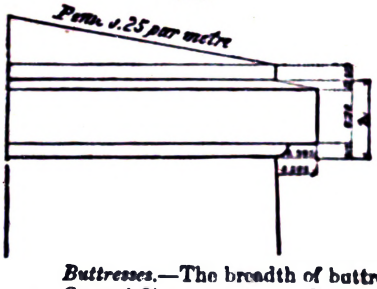
1417.



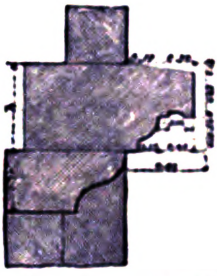
1418.

1419.

1420.




1421.



1422.

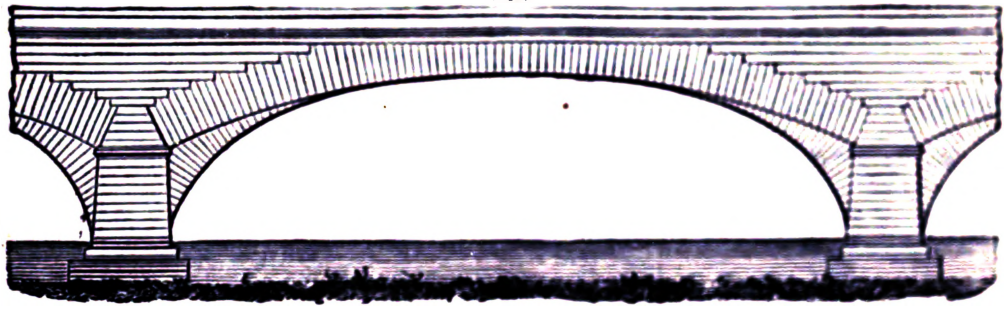
1423.

*Buttresses.*—The breadth of buttresses will be equal to the thickness of the plinth.

*General Observation on the Construction of Arches.*—We strongly recommend the placing of headers here and there in arches of wide span; the headers should be of cut stone of a mean depth twice that of the materials employed in the construction of the arches; iron cramps, set in cement, may be used to hold firmly together the stones composing the headers. This latter arrangement has been tested by experience.

The arches of the celebrated bridge built by Perronet, over the Seine at Neuilly, one of which is shown in Fig. 1424, are 128 ft. span, and the radius of the circle, of which the coincident portions

1424.



COMPARATIVE TABLE OF THE PRINCIPAL DIMENSIONS OF

| No. | Name of the Work. | Present Dimensions. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of Arches. | Span of the Arches. | Longest Radius. | Rise of the Arches. | Proportion of the Rise to the Span. | Magnitude of the Arc of the longest Radius. | Thickness: Of the Arches at the Crown. | Of the Piers at the Springing. | Of the Abutments at the Springing. |
| | **1st. Semicircular Arches.** | | | | | | | | | |
| 1 | Bridge at Romilly, over the Cheran | 1 | 38·90 | 19·45 | 19·45 | 0·50 | 180° | 1·62 | .. | .. |
| 2 | Bridge at Avignon (Rhone) .. .. | 21 | 31·36 | 15·68 | .. | „ | „ | 0·74 | 6·96 | 26·43 |
| 3 | Aqueduct of Spolette (Italy) .. .. | 10 | 21·44 | 21·44 | .. | .. | .. | .. | 3·57 | .. |
| 4 | Bridge at Maligny .. .. .. .. | 1 | 26·00 | 13·00 | .. | 0·50 | 180° | 0·92 | .. | 3·65 |
| 5 | Bridge at Furand, over the Furand | 1 | 20·00 | 10·00 | .. | „ | „ | 1·00 | .. | 8·50 |
| 6 | Viaduct at Stockport .. .. .. | 22 | 19·80 | 9·90 | .. | „ | „ | 0·84 | 3·04 | .. |
| 7 | Viaduct at La Manse, on the railway from Tours to Bordeaux .. .. | 15 | 15·00 | 7·50 | .. | „ | „ | 0·90 | 3·40 | .. |
| 8 | Viaduct at St. Germain (railway) .. | 20 | 10·00 | 5·00 | .. | „ | „ | 0·95 | 1·90 | .. |
| 9 | Viaduct at Beaugency (railway) .. | 2500 | 8·40 | 4·20 | .. | „ | „ | 0·80 | 1·60 | 2·60 |
| 10 | Roadways over the railway (Tours to Bordeaux) .. .. .. .. .. | 1 | 8·00 | 4·00 | .. | „ | „ | 0·65<br>0·60 | .. | 2·20 |
| 11 | Roadways under the same .. .. | 1 | 7·00 | 3·50 | .. | „ | „ | 0·65<br>0·60 | .. | 2·00 |
| 12 | „ „ | 1 | 5·00 | 2·50 | .. | „ | „ | 0·55 | .. | 1·50 |
| 13 | Aqueducts, on small single arch bridges, under the same .. .. | 1 | 2·00 | 1·00 | .. | „ | „ | 0·29 | .. | .. |
| 14 | „ „ (southern railway) | 1 | 2·00 | 1·00 | .. | „ | „ | 0·20 | .. | .. |
| 15 | „ | 1 | 1·00 | 0·50 | .. | „ | „ | 0·40<br>0·30 | .. | 0·55 |
| | **2nd. Elliptical Arches.** | | | | | | | | | |
| 16 | Bridge at Gignac, over the Herault | 1<br>2 | 48·72<br>25·34 | 35·89<br>12·67 | 13·30<br>12·67 | 0·275 | .. | 1·95 | 7·80 | 11·05 |
| 17 | Bridge at Neuilly, over the Seine .. | 5 | 38·98 | 48·73 | 9·75 | 0·250 | .. | 1·62 | 4·22 | 9·83 |
| 18 | Bridge at Port de Piles (rail), over the Creuse .. .. .. .. .. | 3 | 31·00 | 21·60 | 11·00 | 0·355 | 60° | 1·30 | 5·50 | 7·30 |
| 19 | Bridge at Auzon (railway), over the Vienne .. .. .. .. .. .. | 5 | 20·00 | 14·50 | 6·67 | 0·333 | „ | 1·10 | 2·60 | 10·80 |
| 20 | Bridge at Bordeaux .. .. .. .. | 17 | 26·50 to 20·80 | .. | 8·81 | 0·332 | .. | 1·20 | 4·20 | .. |
| 21 | Bridge at Chavannes .. .. .. | 7 | 13·00 | 9·43 | 4·55 | 0·350 | .. | 0·65 | 4·55 | 6·50 |
| 22 | Bridge over the Brusche (railway in Alsace) .. .. .. .. .. .. | 4 | 10·00 | 7·14 | 3·00 | 0·333 | .. | 0·72 | 1·50 | 2·70 |
| 23 | Bridge over the canal at Ellesmere (England) .. .. .. .. .. | 1 | 4·90 | 3·66 | 1·83 | 0·373 | .. | 0·31 | .. | 0·92 |
| 24 | Pont de l'Alma, over the Seine .. | 1<br>2 | 43·00<br>38·40 | 53·75<br>50·56 | 8·60<br>7·70 | 0·20<br>0·20 | ..<br>.. | 1·50<br>1·50 | 5·00<br>.. | ..<br>10·00 |
| | **3rd. Segmental Arches.** | | | | | | | | | |
| | 1st, 120° and over. | | | | | | | | | |
| 25 | Bridge over Doux, near Tournon .. | 1 | 47·78 | 24·06 | 19·82 | 0·414 | 157° 34′ | 0·85 | .. | .. |
| 26 | Bridge over the Conon (England) .. | 5 | one<br>19·82 | 11·10 | 6·10 | 0·307 | 127° 12′ | 0·92 | 2·44 | .. |

BRIDGES, VIADUCTS, AND AQUEDUCTS CONSTRUCTED IN EUROPE.

| Nature of the Materials of the Arch. | Date of Construction. | Name of Architect, and Observations. | Dimensions according to our Formula. | | | | | General Formula and Observations. |
|---|---|---|---|---|---|---|---|---|
| | | | Radius serving to determine the Depth at the Crown. | Depth at the Crown. | | Thickness at the Plane of the Springing, according to the general value of C. | | |
| | | | | According to the General Formula. | Taking into account the Radius and the Materials. | Of the Piers. | Of the Abutments. | |
| Freestone .. .. | 1785 | Garella .. .. .. | 19·45 | 1·66 | 1·65 | .. | 7·03 | C { 0·30 + 0·07 R. / 0·30 + 0·08 R. |
| „ | 1177 | Bénédic. The abutments include walls | 15·68 | 1·40 | 1·24 | 4·20 | 5·74 | E = 0·20 + 0·20 (R + 2 C) |
| .. .. .. | 741 | The piers of this aqueduct are 89 mètres high, with a base of the same thickness as at the springing; the total height of the work = 130 mètres | .. | .. | .. | .. | .. | P { 2·50 × C. / 3·00 × C. — The abutments should have an exterior talus of 0·20 per metre. |
| Freestone .. .. | .. | .. .. .. | 13·00 | 1·21 | 0·98 | 3·63 | 4·83 | |
| „ | 1834 | Montluisant .. .. | 10·00 | 1·00 | 0·70 | 3·00 | 3·80 | The piers should have a talus of $\frac{1}{10}$. |
| Bricks, and a small quantity of freestone | .. | Mean height of the piers = 20 mètres. No talus | 9·90 | 0·99 | 0·82 | 2·97 | 3·76 | |
| Slightly hewn stone | 1847 | Morandier .. .. | 7·50 | 0·83 | 0·80 | 2·49 | 2·95 | |
| Unhewn millstone grit, ordinary hydraulic lime | 1845 | E. Flachat .. .. | 5·00 | 0·70 | 1·00 | 2·10 | 2·09 | |
| Hewn stone .. .. | 1845 | Thoyot. Talus of the piers = 0·04 | 4·20 | 0·64 | 0·41 | 1·60 | 1·81 | |
| Slightly hewn stone | .. | .. .. .. | 4·00 | 0·62 | .. | .. | 1·72 | |
| „ „ | .. | Thickness of the abutments uniform | 3·50 | 0·59 | .. | .. | 1·58 | |
| „ „ | .. | .. .. .. | 2·50 | 0·50 | .. | .. | 1·24 | |
| Unhewn stone .. | .. | .. .. .. | 1·00 | .. | 0·30 | .. | 0·70 | |
| Slightly hewn stone | .. | Carvallo .. .. .. | 1·00 | .. | 0·30 | .. | 0·70 | |
| Unhewn stone .. | .. | With light masses of embanking | 0·50 | 0·34 | .. | .. | 0·55 | |
| | | | | | | | | C = 0·30 + 0·05 R. R = 1·195 × Q − 1·366 F. |
| Freestone .. .. | 1777 to 1793 | Garipuy .. .. .. | 39·60 | 2·28 | 1·28 | 6·84 | 13·15 | |
| „ | 1774 | Perronet .. .. .. | 32·90 | 1·94 | 1·94 | 5·82 | 10·90 | |
| „ | 1848 | Beaudemoulin and Croizette-Desnoyers | 21·60 | 1·38 | 1·38 | 4·14 | 7·50 | |
| Hewn stone .. .. | 1848 | „ „ | 14·55 | 1·03 | 1·02 | 3·09 | 5·18 | |
| Bricks, with freestone bonders | 1813 to 1822 | Deschamps .. .. | 19·30 | 1·26 | 1·20 | 3·78 | 6·75 | |
| Freestone .. .. | 1787 | Gauthey .. .. .. | 9·17 | 0·76 | 0·52 | 2·28 | 3·40 | |
| Bricks .. .. .. | 1845 | Bazaine & Chaperon | 7·76 | 0·68 | 0·50 | 1·70 | 2·94 | |
| „ | .. | Telford .. .. .. | 3·28 | 0·47 | 0·35 | .. | 1·47 | |
| Millstone grit, with Vassy cement | 1855 | De Lagalisserie and Darcel | 39·50 / 33·00 | 2·27 / 1·95 | 2·00 / 1·65 | 6·00 | 11·10 | Millstone grit with Vassy cement offers as much resistance as Dumbarton. C = 0·20 + 0·07 R. $R = \frac{Q}{2 \sin. \alpha}$. $\sin. \alpha = \frac{Q}{2R}$. |
| Slightly hewn stone | 1545 | .. .. .. | 24·06 | 1·98 | .. | .. | 8·60 | |
| Freestone .. .. | 1809 | Telford .. .. .. | 11·10 | 1·08 | 0·72 | 2·16 | 4·18 | |

COMPARATIVE TABLE OF THE PRINCIPAL DIMENSIONS OF BRIDGES.

| No. | Name of the Work. | Present Dimensions. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of Arches. | Span of the Arches. | Longest Radius. | Rise of the Arches. | Proportion of the Rise to the Span. | Magnitude of the Arc of the longest Radius. | Thickness: Of the Arches at the Crown. | Of the Piers at the Springing. | Of the Abutments at the Springing. |
| | 2nd, from 120° to 90°. | | | | | | | | | |
| 27 | Bridge at Vérone, near Vieux-Château | 3 | one 44·50 | 28·62 | 10·90 | 0·245 | 102° 04′ | 1·62 | 11·05 | 10·40 |
| 28 | Bridge over the Taaf (England) | 1 | 46·47 | 29·42 | 11·37 | 0·245 | 104° 20′ | 1·13 | .. | .. |
| 29 | Specimen of passage over railway | 1 | 15·20 | 10·75 | 3·15 | 0·207 | 90° 00′ | 0·90 | .. | 4·65 |
| | 3rd, from 90° to 60°. | | | | | | | | | |
| 30 | Covered bridge at Florence (Italy) | 3 | 29·25 | 21·20 | 5·85 | 0·200 | 87° 17′ | 1·62 | 7·85 | 8·77 |
| 31 | Bridge at Grosvenor, over the Dee (England) | 1 | 61·00 | 44·23 | 12·20 | 0·200 | 87° 16′ | 1·22 | .. | 14·64 |
| 32 | Bridge at Munich (Bavaria) | 3 | 31·20 | 26·00 | 5·20 | 0·167 | 73° 44′ | 1·30 | 2·92 | 9·75 |
| 33 | Bridge at Glasgow | 3 | 17·70 | 13·33 | 3·35 | 0·189 | 85° 10′ | 0·76 | 2·75 | 3·81 |
| 34 | Specimen of passage over railway | 1 | 12·00 | 10·00 | 2·00 | 0·167 | 73° 44′ | 0·75 | .. | 1·90 |
| 35 | Bridge at Brunoy | 3 | 5·85 | 5·85 | 0·79 | 0·135 | 60° 00′ | 0·65 | 1·13 | 3·25 |
| | 4th, from 60° to 40°, and under. | | | | | | | | | |
| 36 | Bridge at Homps, over the Ande | 3 | 21·40 | 21·40 | 2·87 | 0·135 | 60° 00′ | 1·30 | 3·57 | 8·77 |
| 37 | Bridge at Val-Benoist Railway (Belgium) | 5 | 20·00 | 20·00 | 2·68 | 0·135 | 60° 00′ | 1·00 | 2·50 | .. |
| 38 | Bridge at Etaples Railway (Amiens to Boulogne) | 15 | 14·00 | 13·85 | 1·90 | 0·136 | 60° 44′ | 0·70 | 1·75 | 6·00 |
| 39 | Pont d'Jéna, over the Seine (Paris) | 5 | 28·00 | 31·35 | 3·30 | 0·105 | 53° 05′ | 1·44 | 3·00 | 9·75 |
| 40 | Specimen of passage under railway | 1 | 8·00 | 8·70 | 1·00 | 0·125 | 56° 8′ 40″ | 0·70 | .. | 2·40 |
| 41 | „ „ (Northern Railway) | 1 | 7·40 | 8·50 | 0·90 | 0·122 | 51° 36′ | 0·65 | .. | 3·86 |
| 42 | Pont au Double, over the Seine (Paris) | 1 | 31·05 | 41·67 | 3·00 | 0·096 | 43° 42′ | 1·60 | .. | .. |
| 43 | Pont de la Concorde, Seine (Paris) | 1 | 31·18 | 42·20 | 2·99 | 0·096 | 43° 20′ | 1·13 | .. | .. |
| | | 2 | 28·26 | 38·86 | 2·66 | 0·094 | 42° 39′ | 1·05 | 2·92 | .. |
| | | 2 | 25·34 | 42·14 | 1·95 | 0·077 | 35° 00′ | 0·97 | .. | 16·24 |
| 44 | Bridge at Moret, over the Loing | 3 | 25·30 | 46·77 | 1·85 | 0·073 | 31° 20′ | 1·30 | 2·43 | .. |
| 45 | Bridge at Nemours, over the Loing | 3 | 16·24 | 30·21 | 0·97 | 0·060 | 15° 35′ | 0·97 | 1·95 | 4·87 |

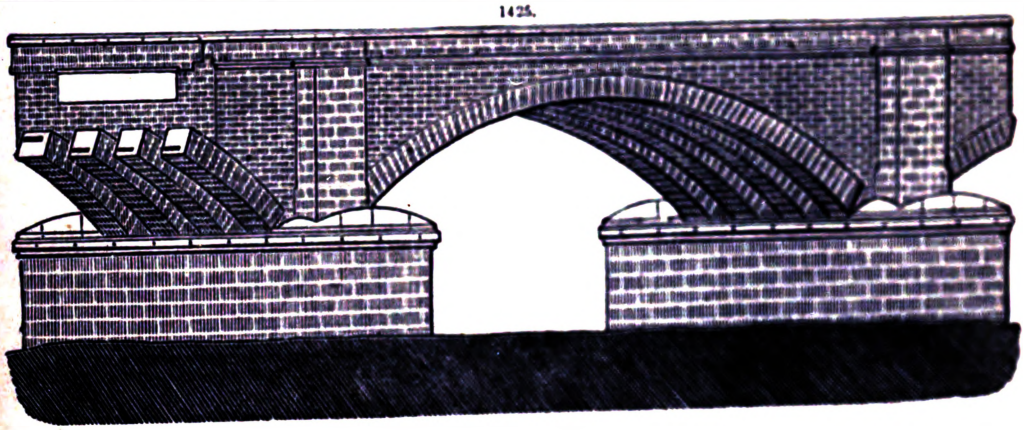
of the outer segmental arch are parts, is 160 ft. A comparison of this bridge with a bridge on the same plan, after the designs of Roy, will be found at No. 17 in the Table, page 698.

Along the line of the Highland Railway numerous bridges and viaducts have had to be erected. Fig. 1425 is of the viaduct which spans the river Conon, in Ross-shire. From circumstances it was necessary that this bridge should cross the river on a skew of 45° to the stream, and as there were rock foundations, there was no difficulty to contend with beyond that of 4 ft. or 5 ft. of water in the channel of the river to reach the rock. The peculiarity of the skew with the river at this place could have been more easily provided for by the adoption of iron girders from pier to pier, but as it was found that iron girders would be fully as expensive and not so permanent as a stone bridge, and as there were admirable quarries in the neighbourhood, Joseph Mitchell, the engineer of the line, resolved to construct this bridge on a skew of 45° with the river, by a series of right-angled ribs or arches spanning from pier to pier. The bridge consists of five arches of 73 ft. span each, the arches being constructed of four ribs, each 3 ft. 9 in. wide; the arch stones are 4 ft. deep at the springing, and 3 ft. deep at the crown. The key-stones of the centre part of each arch were made to connect with each other, as were the stones in the haunchings of the arches, and some cramps of iron were inserted at the joints to connect the ribs. The work was

VIADUCTS, AND AQUEDUCTS CONSTRUCTED IN EUROPE—*continued*.

| Nature of the Materials of the Arch. | Date of Construction. | Name of Architect, and Observations. | Dimensions according to our Formula. | | | | | General Formula and Observations. |
|---|---|---|---|---|---|---|---|---|
| | | | Radius serving to determine the Depth at the Crown. | Depth at the Crown. | | Thickness at the Plane of the Springing, according to the general value of C. | | |
| | | | | According to the General Formula. | Taking into account the Radius and the Materials. | Of the Piers. | Of the Abutments. | |
| | | | | | | | | C = 0·30 + 0·05 R. |
| Freestone .. .. | 1354 | .. .. .. | 28·62 | 1·73 | .. | 5·19 | 9·82 | |
| „ | 1756 | Edward .. .. .. | 29·42 | 1·77 | .. | .. | 10·06 | |
| Slightly hewn stone | .. | .. .. .. | 10·75 | 0·88 | 0·85 | .. | 3·94 | |
| | | | | | | | | 60° C = 0·30 R + 0·04 R. |
| Freestone .. .. | 1600 | .. .. .. | 21·20 | 1·34 | 1·24 | 4·02 | 7·06 | |
| Granite .. .. .. | 1832 | Harrison .. .. .. | 44·23 | 2·47 | 1·30 | .. | 14·93 | Granite having a resistance quadruple of the mean resistance of the other materials for which our formulæ are established, this difference of thickness at the crown need cause no surprise. |
| Freestone .. .. | 1814 | Wiebeking .. .. | 26·00 | 1·45 | 1·45 | 4·35 | 8·87 | |
| | 1835 | Telford. The abutments are strengthened by curved buttresses | 13·33 | 0·95 | 0·70 | 2·85 | 4·77 | |
| Slightly hewn stone | 1850 | Busch .. .. .. | 10·00 | 0·74 | 0·74 | .. | 3·64 | |
| Freestone .. .. | 1784 | Perronet .. .. .. | 5·85 | 0·54 | 0·40 | 1·35 | 2·28 | |
| | | | | | | | | 50° C = 0·30 + 0·03 R. |
| | | | | | | | | 40° C = 0·30 + 0·02 R. |
| „ | 1785 | Ducros .. .. .. | 21·40 | 1·25 | 1·16 | 3·75 | 7·36 | |
| .. .. .. | 1832 | .. .. .. | 20·00 | 1·10 | .. | 3·30 | 6·86 | |
| Bricks .. .. .. | 1847 | Bazaine .. .. .. | 13·85 | 0·85 | 0·81 | 2·55 | 4·87 | If the whole arch is of brick, we should only allow 0·10 at the crown. |
| Freestone .. .. | 1809 | Lamandé .. .. .. | 31·35 | 1·34 | 1·34 | 4·02 | 10·40 | |
| Slightly hewn stone | 1850 | Busch .. .. .. | 8·70 | 0·61 | 0·60 | .. | 3·18 | |
| „ „ | 1846 | .. .. .. | 8·50 | 0·57 | 0·55 | .. | 3·09 | |
| Unhewn millstone grit with Vassy cement | 1847 | De Lagalisserie .. | 41·67 | 1·28 | 1·65 | .. | 13·47 | Comparing millstone grit with cement to freestone. |
| Freestone .. .. .. | 1787 to 1792 | Perronet. The thickness of the abutment is not excessive, it includes two counter-forts of 7·15 in. length | 42·20<br>38·86<br>42·14 | 1·28<br>1·17<br>1·14 | .. | 3·51 | 13·53 | |
| „ | 1771 | Perronet .. .. .. | 46·77 | 1·24 | .. | 3·72 | 14·97 | |
| „ | 1805 | Designs by Perronet | 30·21 | 0·90 | .. | 2·70 | 9·26 | |

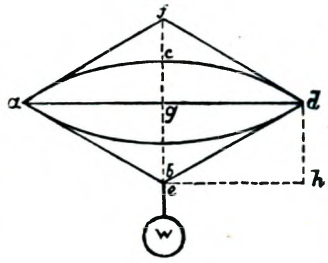
1425.



successfully accomplished, and constitutes a very perfect piece of bridge masonry. The total length of the bridge is 540 ft., and the height 45 ft. from the bed of the river. The north abutment is founded 304 ft. lower down the river than the south. The whole bridge was constructed for a single line of rails.

*J. A. Roebling's System of Bridge-building: the Parabolic Truss.*—Let $a\,c\,b$ and $a\,d\,b$, Fig. 1426, represent parabolic curves of the same deflection and span. The upper curve forms an upright arch, which presses against the points $a$ and $b$. If these points are connected by the chord $a\,b$, and this chord balances the pressure at $a$ and $b$, the chord and the arch will be in equilibrium and at rest.

1426.




The inverted parabolic arch $a\,d\,b$, freely suspended between $a$ and $b$, will, on the other hand, produce an inside pressure upon these two points of support. If the two arches are equally and uniformly loaded, their strains at $a$ and $b$ will be the same, and in the directions of their respective tangents $a\,f$, $b\,f$, and $a\,e$, $e\,b$. We may therefore remove the chord $a\,b$, and in its place suspend the arch $a\,d\,b$; then th. outward pressure, exerted by the upright arch upon $a$ and $b$, will be met and balanced by the inward pressure at $a$ and $b$, produced by the suspended arch $a\,d\,b$. The two arches are therefore in equilibrium, without any intermediate chord.

In a bowstring girder or arch nearly the same amount of material must be expended in the chord $a\,b$ which is required in the arch itself. But the chord adds nothing to the supporting power of the arch. On the other hand, by suspending the subverted arch $a\,d\,b$, we may dispense with the chord, and at the same time we have *doubled* the supporting power of the system. The great economy of the parabolic beam is therefore apparent at a glance. All that is required in practice is to provide sufficient panelling, and light bracing inside of the arches, in order to preserve their form and equilibrium under variable loads. It will be shown hereafter that a greater amount of material must be expended to obtain the same strength in other systems of girders and trusses.

To ascertain the forces of tension and compression at $a$ and $b$, produced by the upright and suspended arch, draw the parallelogram $a\,f\,b\,e$, the sides forming tangents to the curves. The pressures caused by the upright arch will then be represented by $a\,f$ and $b\,f$, and the tension caused by the suspended arch is measured by $a\,e$ and $b\,e$. Suppose the weight W to represent the whole weight of the upright arch, then this weight will act through the linear braces $f\,a$ and $f\,b$ upon $a$ and $b$, and its relative magnitude is represented by the diagonal $f$ E, which is the resultant of the two forces $f\,a$ and $f\,b$. Let the pressure at $a$ or $b$ be denoted by P, then is $\mathrm{W} : \mathrm{P} = e\,f : a\,f$; and therefore, $\mathrm{P} = \mathrm{W}\,\frac{a\,f}{e\,f}$. Let $x$ represent the deflection, or verse sine, $g\,c$ or $g\,d$, $y$ — half the chord $a\,g$ or $g\,b$; and suppose the curves to be parabolas, then $g\,c$ will be equal to $c\,f$, or, $x = \frac{1}{2}\,g\,f = \frac{1}{2}\,g\,\mathrm{E}$; and $\overline{a\,f}^2 = \overline{a\,g}^2 + \overline{g\,f}^2 = y^2 + 4\,x^2$, or, $a\,f = \sqrt{y^2 + 4\,x^2}$. Substituting this value in the equation for P, and $4\,x$ for $e\,f$, we have $\mathrm{P} = \frac{\mathrm{W}}{4\,x}\sqrt{y^2 + 4\,x^2}$. The tension T, caused by the suspended cable at $a$ and $b$, is equal to P, and found by the same formula.

As an example, let us suppose the span of the arch to be 500 ft., its verse sine 50 ft., and its total weight 500 tons; to find the pressure or tension at the points of support, we then have

$$\mathrm{P} = \frac{500}{4 \times 50}\sqrt{\overline{250}^2 + 4 \times \overline{50}^2}.$$

$$\mathrm{P} = 500 \times \frac{269{\cdot}25}{200} = 500 \times 1{\cdot}34.$$

$$\mathrm{P} = 670 \text{ tons.}$$

The figure 1·34 represents a variable coefficient, which is dependent upon $x$ and $y$, but independent of the weight W. We may therefore, for convenience sake, compose a table of coefficients which will facilitate rapid calculations. The following Table gives the coefficients for versed sines of $\frac{1}{8}$ of the span to $\frac{1}{15}$:—

| V. S. | $\frac{1}{8}$ | $\frac{1}{9}$ | $\frac{1}{10}$ | $\frac{1}{11}$ | $\frac{1}{12}$ | $\frac{1}{13}$ | $\frac{1}{14}$ | $\frac{1}{15}$. |
|---|---|---|---|---|---|---|---|---|
| Coe. | 1·118 | 1·23 | 1·346 | 1·463 | 1·58 | 1·70 | 1·82 | 1·94. |

As an example, suppose a span of 1000 ft., verse sine $\frac{1}{8}$, or 125 ft., and load 1000 tons. The coefficient of pressure or tension in the Table is 1·118, therefore the pressure or tension is

$$1000 \times 1{\cdot}118 = 1118 \text{ tons.}$$

As another example, suppose the same span and load with a verse sine of $\frac{1}{15}$ of the span = 66·66 ft., then the coefficient in the Table is 1·94, and therefore the pressure or tension is

$$1000 \times 1{\cdot}94 = 1940 \text{ tons.}$$

It may be necessary to calculate the exact length of the arch, suspended or upright, measured by the curve. Let Z denote one-half the length of the curve, then is $\mathrm{Z} = \sqrt{y^2 + \frac{4}{3}\,x^2}$. This formula applies to a parabola, and is much more simple than the formula for a true catenary. It is sufficiently correct for practice, provided $x$ is not greater than $y$.

To determine the deflection $x$ from the length of the curve and of the span, the following

equation will answer: $x = \sqrt{\frac{3}{4}(Z^2 - y^2)}$. These formulas are needed in order to calculate the rise or fall of an arch, due to its expansion or contraction from variations of temperature.

This diagram represents half a parabola, with its ordinates and abscissæ. Now it is a property of the parabola that $x : x' = y^2 : y'^2$; from this we deduce $x' = \frac{x}{y^2} y'^2$; also, $x'' = \frac{x}{y^2} y''^2$, and so on. When, therefore, $x$ and $y$ are known, we can calculate the ordinates $x'$, $x''$, $x'''$, $x''''$, for any abscissa. This will enable us to lay down the curve of the upright arch, or to calculate the length of suspenders for the suspended cable.

To ascertain the compression of the arch at its crown $c$, Fig. 1426, or the tension of the cable at its lowest point $d$, draw the lines $c\,h$ and $b\,h$ parallel to $g\,b$ and $g\,c$ in Fig. 1427; then the diagonal $b\,c$ represents the strain at $b$, while $c\,h$ represents the horizontal strain at $d$ or $c$, and $b\,h$ represents the vertical pressure produced upon $b$ or $a$, either by the arch or cable. $b\,h$ being equal to $c\,d$ or $2\,x$, of course the sum of the vertical pressures at $a$ and $b$ is equal to the whole weight of the arch or W.

1427.

In a similar manner can the compression or tension of the arch be ascertained at any other point of the curve by simply laying down a tangent and drawing out its parallelogram. The tension or compression is thus found to increase gradually from the centre to the points of support.

By laying down the curves accurately on a large scale, all the different strains may be measured by the scale sufficiently accurate for all practical purposes.

*General Description.*—The three openings of this bridge are spanned by two parallel continuous parabolic trusses, 1184 ft. in length, at a distance of 14 ft. apart in the clear: the floor beams for support of the track resting upon the lower chords. This superstructure is firmly fixed upon one of the two middle piers, while it rests upon roller-plates on all the other piers. This arrangement, therefore, admits of free contraction and expansion, caused by changes of temperature. It will be noticed that the towers which support the cables on the middle piers, form integral parts of the movable structure, and consequently will change their position in unison with the other parts of the work, when affected by contraction or expansion. The cables together with the arches form one united system, all moving together uniformly when thus influenced.

The railway track is supported at intervals of 5 ft. by rolled iron beams of 12 in. depth and 21 ft. 5 in. in length. The rails rest upon wooden stringers, 12 × 12, which are strengthened in depth by timber bridgings, 6 × 12, fitted in between the iron beams. A longitudinal iron beam of 9 in. depth underneath the bridging, suspended by bolts to the wooden stringer, adds further to the depth of bearing, which is wanted to distribute the concentrated weight of the locomotive drivers, and thus diminish their kneading action. Every second cross beam is suspended to the cables by means of suspenders, but each of the beams is also firmly riveted to the lower chords by sixteen rivets of $\frac{7}{8}$ in. diameter. This union forms the only connecting link between the arches and the cables.

There is one truss on each side of the track, and each is double throughout from end to end, leaving an open space 24 in. in width between the posts. In the centre of this space the cable is freely suspended in a vertical plane, parallel to the trusses; the suspenders run down in the same plane; so also do the wire-rope stays, which pass over the towers below the cables. Where the stays cross the suspenders, they are united with them by wire wrappings, for the purpose of preserving their straight lines, and to prevent oscillations.

The principal features, which give supporting strength as well as stiffness to the trusses, are the arches. The cables, which co-operate with the arches, are designed for strength alone, without adding much to stiffness. An additional source of strength as well as stiffness is obtained by the wire-rope stays, six on each tower; these are also very efficient in preserving the equilibrium between the spans under the action of variable loads, and also in relieving the arches at the haunches, where assistance is most needed.

At the extreme ends of the trusses four light double wire-rope stays are added to give additional strength and stiffness to those points.

At the first glance this plan may appear a complicated arrangement, defeating its own end by the want of internal harmony among its different parts. But no view could be more mistaken. In place of exhibiting a want of harmony, this system will be found in its practical working so co-operative and mutually supporting in its various parts, that nothing will be left to desire. No system is possible which, under the action of passing and variable loads, will be affected with perfect uniformity in all its parts, so that all the different members will be exposed to the same uniform proportional strain. Uniformity of strain in a plate-girder, in a lattice-girder, or in any other triangular or panelled truss, is out of the question. The arch alone, upright or suspended, comes nearer than any other system toward fulfilling this condition. When a load is placed upon any one point of the arch, the compression or tension thereby produced upon its section will be felt nearly alike throughout its whole extent, so long as its statical form is maintained. The capacity of the arch to maintain its form is strongest about the centre. Impressions upon the haunches are more apt to produce dislocations in other corresponding parts. To meet this weakness, stays are introduced next to the towers. So far as they extend, they are strong enough to support the maximum weight of that part of the structure as well as the load. Each stay in connection with the floor and tower forms a fixed triangle. This simple system of stays, as here designed, is the perfection of trussing. Nothing can be more perfect, or more simple, effective, and economical.

In the Niagara, Cincinnati, and Alleghany bridges, the conditions upon which the true action of stays depend are only partially fulfilled, because of the different material of the towers and the neutrality of the floor. And yet with these drawbacks, the stays in these works answer such an admirable purpose, that they could not be supplanted by another arrangement. But in the plan before us all parts are composed of the same material, and are allowed to expand and to contract freely, and consequently their harmonious action cannot be disturbed on that score.

Suppose the section of the arch was doubled, and made strong enough to support a maximum load and the superstructure; and suppose, further, that its ends were connected by a chord strong enough to resist the thrust; all that would then be needed would, by common consent, be spandrils of sufficient stiffness to preserve its form under the action of variable loads. No engineer would doubt the stability of this simple arch. Now, in the plan before us, we employ the same arch, but of only half the section. This deficiency of strength is made up by the suspended arch; and in place of heavy spandrils we introduce a light panel-trussing throughout its whole extent, which will be found more effective in reality than any system of spandrils can possibly be made. This panel-trussing, judging from experience on the Niagara Bridge, will be found abundantly effective to preserve the form of the arch. If there were no adjoining spans, and if there were no necessity for towers for the support of the cables, nothing more would be needed. But the towers being there, the application of stays becomes at once one of the most economical as well as most efficient means to still further secure the stability of the whole system. Only fourteen panels are left without stays in the centre opening, reducing this distance to 280 ft. In this space the arch and the panel-work have to maintain their form alone, not counting upon the assistance of the cables. With reference to stiffness alone, the plan before us may also be considered in the light of a simple bowstring-girder, with this difference in favour of the Parabolic Truss, that the haunches of the arch are greatly assisted by the stays.

The harmony of action between the arches and cables, when under the influence of variable loads, now remains to be considered. Inside of the space of the central opening, between the two longest stays, a distance of 280 ft., a want of uniformity of action is utterly impossible, because the least impression upon the arch will be equally felt by the cable throughout its whole extent, and will be checked by the upward resistance of the superstructure. As the cable becomes depressed, every other point tends to rise, but is prevented by the weight and stiffness of the truss, the arch, and the panels. Considering now that the weight of the middle span is 640 tons, the local impression made by a 40-ton locomotive will be no more than is due to the natural elasticity of the material composing the truss. The cables being the most sensitive members of the system, their action will greatly tend to spread every local impression over a large extent, and thus neutralize its effects by engaging all parts of the system to resist.

So far as the stays extend, no local depression whatever can be produced, because every attachment of stay forms a fixed point, which, in connection with the arches, cables, and panel-braces, will be found sufficiently rigid to resist the severest local action beyond that due to the natural elasticity of the materials. Roebling is positive in this statement, because his observations on the suspension-bridges he built fully justify him in making it. If any one will take the trouble to scrutinize the action of the Niagara Bridge under the passage of a single heavy locomotive and tender with sufficient care and attention, and, by means of a level placed in one of the towers, will observe the progressive depressions of that structure, which take place from the tower toward the centre, he will discover scarcely any depression inside of the reach of the stays. Beyond the stays, toward the centre, the depression increases rapidly, and becomes greatest in the centre. Similar facts will be noticed on the Cincinnati Bridge. under the action of a number of heavily-laden teams, following each other in close succession.

The cables and stays are securely fixed upon the cast-iron saddles, which are mounted upon the tops of the wrought-iron towers by means of cushions, held down by screws. The height of the towers being 62 ft. above the base, and the supporting columns of an elastic material, they will yield a little, when one span is fully taxed with a maximum load, while the adjoining spans are empty. This yield will be imperceptible to the eye, but will no doubt be susceptible of measurement. And as this movement will not result from the free working of the different members of the system, but will be entirely due to the elastic yield of the materials, it may be repeated indefinitely without impairing the integrity and safety of the structure.

Since wire possesses a much greater degree of elasticity than bar-iron, one very great advantage of the cables and stays will be, that ordinarily, when not taxed by any load, the greater part of the weight of the structure will be borne by the wire. Under the action of light loads, the cables and stays will continue to bear the greater share; but when taxed with heavy trains, then the arches will also receive their full proportion. When the structure is relieved, the cables and stays will again contract and support the largest share. And so long as this process is kept within the limits of natural elasticity, allowing for an ample margin, the structure will remain perfectly safe and intact.

Each of the two cables is represented as composed of nineteen wire-ropes. Ropes will be found in practice to be the most economical means of forming the cables, also the easiest to put up, and the quickest. Cables made of wire laid parallel may also be constructed by those who have experience in this process, and know how to make a good cable; but the same amount of wire laid parallel into cables will give less strength than the same amount of wire laid into rope, provided the lay in the latter is long, and that its manufacture has been conducted with the necessary care and proper machinery. It is impossible to obtain perfectly uniform tension in a parallel cable, but it is possible to do so in a rope. The cost of the two, per pound, will be about the same, and of course the strongest should be preferred.

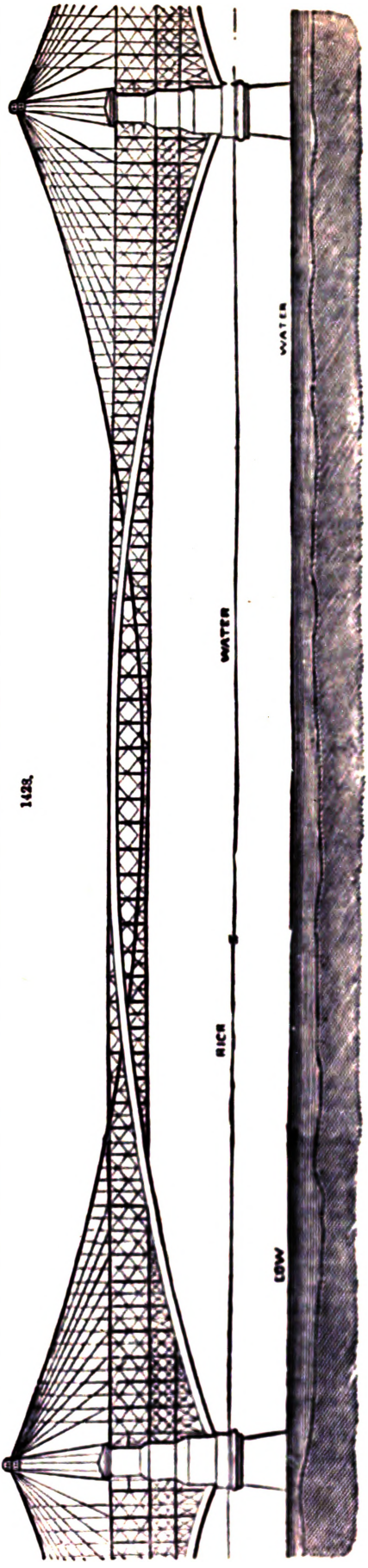
In place of making the cables of wire, they can also be made of iron or steel bands, provided the bands are rolled full length, so that they can be laid into the cable without splicing. The rolling of bands, say 4 in. wide and $\frac{1}{4}$ in. thick, and 1000 ft. or more in length, is a process which

has never been attempted. But this process is perfectly practicable on a continuous mill constructed on the same principle as is Bedson's train.

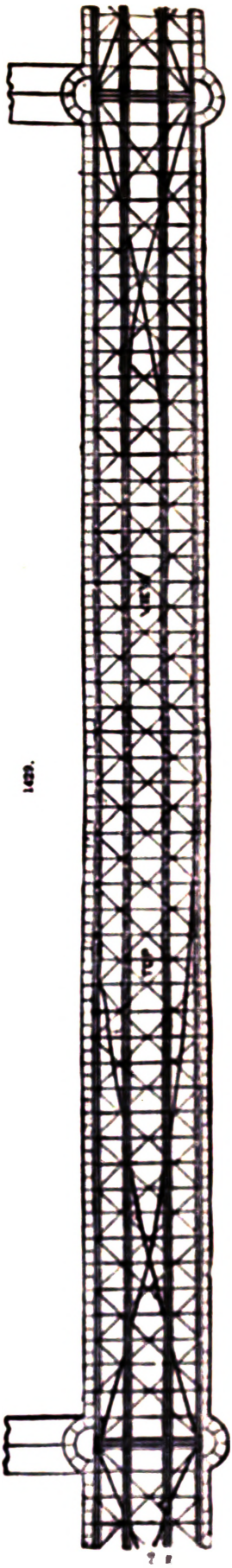
The greatest depth of the superstructure in the central span is 44 ft., while its width is only 21 ft. 5 in. It is plain that this width is not enough to ensure sufficient lateral stability in heavy storms, or to prevent all horizontal oscillations under the passage of rapidly-moving trains. It must be observed that we are explaining the principle of Roebling on a bridge with a centre opening of 500 ft. and two side openings of 300 ft. each in the clear at low water. Where one or two tracks are wanted for the accommodation of common travel, in connection with railroad traffic, either the floor for common travel may be placed overhead, above the railroad floor, or on the same level. If the latter arrangement is preferred, then an increased width becomes necessary, and this will still more add to horizontal stability. To ensure lateral strength, Figs. 1428, 1429, two wire-cables in horizontal parabolic curves have been laid down, anchored to one of the piers, suspended to the lower floor and fastened at intervals to the beams, which will ensure an ample degree of safety under all circumstances. These horizontal cables, forming one system with the flooring, will expand and contract alike with the superstructure; they can consequently be screwed up tight, to ensure their efficiency.

The top chords as well as the arches are sufficiently braced among themselves, horizontally, to impart to the superstructure a degree of internal rigidity; and the same system is also carried out vertically between opposite posts, every 20 ft., so far as the arches *rise above* the top chords.

*Supporting Power of Stays.*—The plan of stays is illustrated by Fig. 1430: $a\,b$ represents the tower; $a\,k$, the floor, at right angles to it; and $b\,c$, $b\,d$, $b\,f$, $b\,g$, and $b\,h$, are the six stays, their respective lengths marked in feet,




1428.



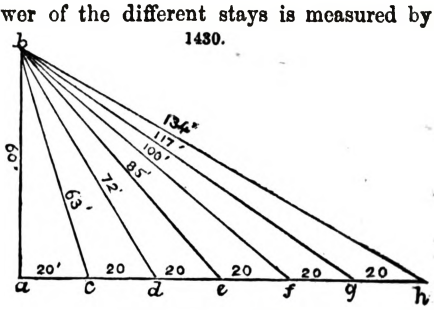
1429.

fractions omitted. It is plain that the supporting power of the different stays is measured by the ratio of the height of tower to their different lengths. Thus, if we denote the supporting power of the stay $b\,c$ by P, its ultimate strength by U, we have $P : U :: 60 : 63$; and $P = U \frac{60}{63}$.

In the same way, for $b\,d$, $P : U :: 60 : 72$; and

$$P = U \frac{60}{72}.$$

The ultimate strength of each of these stays is assumed equal to 100 tons, and we therefore get their supporting power as follows:—




| | | | | | | | Tons. |
|---|---|---|---|---|---|---|---|
| For | $b\,c$ | = | 6000 | ÷ | 63 | = | 95·23 |
| „ | $b\,d$ | = | 6000 | ÷ | 72 | = | 83·33 |
| „ | $b\,e$ | = | 6000 | ÷ | 85 | = | 70·58 |
| „ | $b\,f$ | = | 6000 | ÷ | 100 | = | 60·00 |
| „ | $b\,g$ | = | 6000 | ÷ | 117 | = | 51·25 |
| „ | $b\,h$ | = | 6000 | ÷ | 134 | = | 44·77 |
| Total supporting power of 6 stays, in tons .. .. .. .. | | | | | | | 405·19 |
| „ „ „ 24 „ „ .. .. .. .. | | | | | | | 1620·76 |
| Allow $\frac{1}{5}$ of ultimate strength .. .. .. .. .. .. .. | | | | | | | 324·15 |

Each stay produces a horizontal strain upon the lower chord, which is to its supporting power or vertical action, as is the base of the triangle to its height. Thus the horizontal action of the stay $b\,c$ is represented by the base-line $a\,c = 20$, and its vertical action by $a\,b = 60$, and its direct action by $b\,c = 63$. If, therefore, the horizontal action is denoted by $x$, we find its value for

| | | | | | | Tons. |
|---|---|---|---|---|---|---|
| $b\,c$ | $x$ | = | $100 \times \frac{20}{63}$ | = | 31·74 |
| $b\,d$ | $x$ | = | $100 \times \frac{20}{72}$ | = | 55·55 |
| $b\,e$ | $x$ | = | $100 \times \frac{20}{85}$ | = | 70·58 |
| $b\,f$ | $x$ | = | $100 \times \frac{20}{100}$ | = | 80·00 |
| $b\,g$ | $x$ | = | $100 \times \frac{100}{117}$ | = | 85·47 |
| $b\,h$ | $x$ | = | $100 \times \frac{120}{134}$ | = | 89·55 |
| Aggregate ultimate horizontal action of 6 stays, in tons .. .. | | | | | 412·89 |
| Allow $\frac{1}{5}$ .. .. .. .. .. .. .. .. .. .. .. .. .. .. | | | | | 82·58 |

| | Tons. |
|---|---|
| The weight of the central span is, in tons .. .. .. .. .. .. .. | 642 |
| We will assume it at .. .. .. .. .. .. .. .. .. | 650 |
| The greatest possible transitory load which can be placed upon this span would be a train of locomotives, estimated at the rate of 1½ ton a lineal foot, or for a length of 500 ft., at .. .. .. .. .. .. .. | 750 |
| Therefore, aggregate weight of superstructure and load .. | 1400 |
| Deduct the supporting power of 24 stays, allowing $\frac{1}{5}$ of their ultimate strength .. .. .. .. .. .. .. .. .. .. .. .. .. | 324 |
| Leaves for the support of the arches and the cables .. .. | 1076 |

In order to avail ourselves fully of the economical principle of the Parabolic Truss, it is very evident that the tension produced by the cables should be exactly balanced by the compression of the arches, because the one supports the other. This exact balance of the two forces must exist at the anchor-plates, located at the ends of the superstructure, on the abutments, or on the piers, which serve as such.

These plates firmly hold the ends of the cables, and at the same time serve as supports for the ends of the arches. To further simplify this investigation at its present stage, we will assume that if the tension of the cables and the compression of the arches are equal to each other in the central span, then also the same balance will exist at the anchor-plates. This is not strictly the fact; but for the purpose of making the question plain, and to avoid intricate mathematical formulas, such as would not prove palatable to the practical engineer, and would, moreover, add nothing to the accuracy of this investigation, but, on the contrary, would tend to obscure the subject, at present, however, we assume it to be a fact.

The length of span from centre to centre of towers is 530 ft., and the deflection of the cables is 60 ft. The ratio of deflection, therefore, is 1 : 8·83. From the table of coefficients, we find the ratio of weight and tension for $\frac{1}{9} = 1{\cdot}23$. It will be near enough to assume it here at 1·22.

The span of the lowest tier of arches is 516 ft., and its versed sine or rise 40 ft., and the ratio of deflection is 12·90 ft. The corresponding coefficient of compression in the table we find to be 1·70 ft.

Let us represent the weight to be borne by the cables by $x$, and the weight to be supported by the arches by $y$, then will be the tension of the cables = $1{\cdot}22\,x$, the compression of the arches

$1{\cdot}70\,y$. And since the condition is that the tension of the cables should equal the compression of the arches, therefore is $1{\cdot}22\,x = 1{\cdot}7\,y$. But the aggregate weight to be borne by the arches and cables was found to be 1076 tons. Therefore, $x + y = 1076$, or $y = 1076 - x$. Substitute this value in the previous equation, and we have $1{\cdot}22\,x = 1{\cdot}7\,(1076 - x)$, and $x = 626{\cdot}43$ tons; and also, $y = 1076 - 626{\cdot}43 = 449{\cdot}57$ tons.

From the foregoing we now find that the tension of the cable is $626{\cdot}43 \times 1{\cdot}22 = 764{\cdot}24$ tons.
Compression of the arches is .. .. .. .. .. .. .. $449{\cdot}57 \times 1{\cdot}70 = 764{\cdot}27$ tons, both about the same.

The question may be asked here, why the weight resting upon the arches and cables is not equally divided? If this was done, then it would be necessary to observe the same ratio of span and versed sine for the cables as well as for the arches. But this would reduce the deflection of cables, and thereby diminish their supporting power; or it would increase the rise of the arch and make the structure too top-heavy and too deep in the centre. On further investigation it will be discovered that the proportions here assumed are efficient and economical. The more weight thrown upon the cables, the cheaper the structure will be. But at the same time a certain amount must be reserved for the arches, else they will be too light, and the balance between the centre span and the side spans may be endangered under the action of heavy transitory loads. Each cable is composed of nineteen smaller cables or wire-ropes. The maximum tension of each rope is, therefore, $764 \div 38 = 20{\cdot}10$ tons.

Allowing six times the strength, we have the ultimate strength of each rope, $20{\cdot}10 \times 6 = 120{\cdot}60$ tons.

Each arch is composed of twelve channel-bars, 9 in. deep; we therefore find the maximum compression of each of the channel-bars, $764 \div 24 = 31{\cdot}83$ tons.

Allowing a maximum compressive force of 4 tons to 1 sq. in. of wrought iron, we get the section of each bar, $31{\cdot}83 \div 4 = 7{\cdot}96$ sq. in.

In the estimate of weight this section was assumed at $7\frac{1}{4}$ sq. in. average, at the same time allowing 25 sq. in. section for the top plates in the centre. The compression at the crown being less, the estimate is sufficiently correct for the present.

For much larger spans than 500 ft., it may be found more economical, and at the same time safer, to employ a mild steel for the arches, and also to manufacture the cables out of cast-steel wire. But it would be a mistake to do so in this plan, because the weight of the structure would thereby be too much reduced for safety, and its cost would be enlarged. To ensure a proper degree of stability between the spans under the action of heavy transitory loads, the weight of the structure should not be less than 1 ton to a foot lineal, for a single-track railway, on the supposition that the maximum transitory weights do not exceed $1\frac{1}{4}$ ton the foot. In this country, where 2 tons a foot are required by law, a greater weight of structure will be needed in proportion. But for the railway traffic of America, an allowance of 3000 lbs. maximum load for single track is amply sufficient.

The cables of the side spans form portions of the same curve as those of the middle span. The only difference is, that they are cut off 62 ft. beyond the centre. An exact half-span would measure 265 ft. from centre of tower to end of truss. But the actual length of the truss is 62 ft. more, which makes 327 ft., the object being to make the side spans about 300 ft. in the clear at low-water mark. Whether the cable is anchored at that point or is continued, its tension will not vary, provided its weight or load per unit of length remains the same. In proportioning the arches of the side spans, two conditions have to be fulfilled. Their horizontal thrust at the foot of the towers must balance the horizontal pressure caused by the arches of the central span. Secondly, their horizontal pressure against the anchor-plates must balance the horizontal tension of the cables at those points. These two conditions will determine the proportions of the arches as well as the length of the spans. If, on the other hand, the length of span is fixed, we can also proportion the arches and cables so as to fulfil the above conditions. An easy and practical method for a preliminary investigation, is to lay down the curve of the table, then construct a full arch, similar to the central arch, on thick drawing-paper, cut out its curved outline and lay it down upon the plan; then try its various positions, to find out approximately what length of span and what proportions will about suit. This examination made, we can then calculate the proportions of the arch, its supporting power, and its pressure at the foot and at the anchor-plate. This process, repeated a few times, will bring us near enough to the exact quantities which are required. A practical method like this will be found much more satisfactory, and at the same time easier and more certain than the use of complicated equations.

By lowering the anchor-plate, we shorten the cable until we have reached its centre, which forms an exact half-span. By raising the anchor-plate, we lengthen out the span, and the greatest length will be obtained when the plate is at the level of the upper chord. In that case the arch would have to rise *above* the upper chord. On the other hand, we can also reduce this span to less than a true half-span by moving the anchor-plate back until we meet the upper chord. This point of intersection will then have a strong tendency to rise, which must be met by anchoring to the masonry in such a manner that contraction and expansion from changes of temperature will not be interfered with.

*Strains in Arches and Cables.*—The trusses of the side spans are 327 ft. long, measured from the centre of tower. The arches of the side span form part of a curve whose chord is 352 ft. in length with a versed sine of 18·8 ft. The ratio of deflection to span is therefore as 1 : 18·72, and the coefficient of compression 2·4.

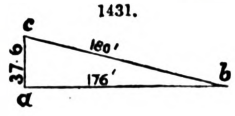
The greatest weight upon the arches of the central span is 450 tons
Or per foot lineal, $450 \div 500 =$ .. .. .. .. .. .. 0·9 „

The weight upon the side arches will be nearly the same per lineal foot, and we will compute

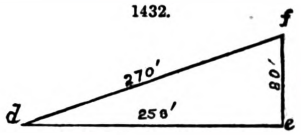
their compression by supposing their whole length weighted down at the same rate. This gives a total weight of $352 \times 0{\cdot}9 = 316{\cdot}8$ tons. Hence their compression at the foot of tower, $316{\cdot}8 \times 2{\cdot}4 = 760{\cdot}32$ tons.

To illustrate:

1431.




1432.



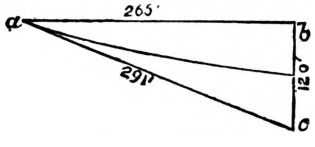

Let $d\,e$, Fig. 1432, represent half the chord of the central arch, 258 ft. long, $e\,f$ twice the height of its rise, equal to 80 ft., then the hypothenuse $d\,f$ will form a tangent to the arch, and will measure 270, omitting fractions. Now, the compression of this arch is represented by $d\,f$, its horizontal thrust by $d\,e$, and its vertical pressure by $f\,e$. Consequently, we find the horizontal thrust of the central arches (since the compression is $449{\cdot}57 \times 1{\cdot}70$)

$$764 : x :: 270 : 258\ x = \frac{764 \times 258}{270}, \text{ or } x = 730 \text{ tons.}$$

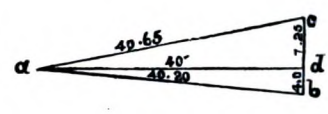
Also let $a\,b$, Fig. 1431, represent half the chord of the side arch, equal to 176 ft., and $a\,c$ its double rise, equal to $37{\cdot}6$, then $b\,c$ represents the tangent, and will measure 180 ft. The horizontal thrust of the arch is then found, $760 : x = 180 : 176\ x = \frac{760 \times 176}{180} = 743$ tons. There is a difference of 13 tons on the part of the side arch, which is readily met by the strength of the lower chord and the stability of the foot of the tower.

Again, let Fig. 1433 represent a rectangular triangle, where $a\,b$ is one-half of the main span or 265 ft., $b\,c$ twice the versed sine of the cables or 120 ft., then $a\,c$ is the tangent, equal to 291, and represents the tension of the cable, while $a\,b$ is its horizontal force, and $b\,c$ its vertical pressure. We therefore find the horizontal force or $x$; $291 : 265 :: 764 : x = \frac{265 \times 764}{291} = 696$ tons.

1433.




1434.




In Fig. 1434, let $a$ be the centre of the anchor-plate, $a\,d$ a horizontal line 40 ft. long, $b\,c$ vertical to it; then make $d\,c = 7{\cdot}25$, and $d\,b = 4{\cdot}0$, $a\,c$ will be $= 40{\cdot}65$, and $a\,b = 40{\cdot}20$; $a\,c$ represents the tangent of the arch, and $a\,b$ the tangent of the cable. In order to find the horizontal force of the cable and arch at $a$, we must first ascertain their relative tension and compression at this point.

| | Tons. |
|---|---|
| The tension of the cable at the top of the tower is .. .. .. .. .. | 764 |
| And in the centre of the curve .. .. .. .. .. .. .. .. .. .. | 696 |
| Difference .. .. .. .. .. .. .. .. .. .. .. | 68 |
| The decrease of tension being nearly uniform, we find the tension at the anchor-plate about .. .. .. .. .. .. .. .. .. .. .. | 712 |
| The compression of the arch at the tower is .. .. .. .. .. .. .. | 760 |
| And at the centre .. .. .. .. .. .. .. .. .. .. .. .. | 743 |
| Difference .. .. .. .. .. .. .. .. .. .. .. .. | 17 |
| The compression at the anchor-plate we find about .. .. .. .. .. | 747 |

We can now ascertain the horizontal force of the cable at the point $a$:

$$712 : x = 40{\cdot}20 : 40{\cdot}00\ x = \frac{712 \times 40}{40{\cdot}2} = 708 \text{ tons.}$$

In the same way the horizontal thrust of the arches is found:

$$747 : x = 40{\cdot}65 : 40\ x = \frac{747 \times 40}{40{\cdot}65} = 753 \text{ tons.}$$

The horizontal pressure of the arches is therefore 27 tons greater than the horizontal force of the cables. This excess is easily met by the resistance of the framing, composed of the upper and lower chords, and by the action of the abutment-stays. A few light tie-rods, extending from the anchor-plates to the lower chords, will also balance this excess. But if there was a necessity to establish an exact balance between the horizontal action of the arches and cables, without changing the length of span, all that would be required is to shorten the full chord of the arch, and to increase its versed sine a few feet, which change would pass them through the upper chord. This change is not desirable, but may be met by increasing the height of the trusses to the same extent. Roebling, however, prefers to leave the proportions as they are, because the ends of the side spans will be found in practice to need more stiffness than other parts of the work, and this will be obtained by an increase of stiffness in the arch.

To add still more to the stiffness of the ends, four light wire-rope stays or ties have been introduced, of sufficient strength to prevent oscillations. To meet the horizontal action of these stays an excess of strength will be found in the upper and lower chords. Another object of these stays is to resist the downward pressure of the three wire-rope stays below the floor. The object of these stays is threefold. First they will assist in preventing oscillations from passing loads; secondly, they will resist the uplifting tendency of heavy storms and hurricanes; and, thirdly, they will

greatly assist the free and easy expansion of the structure caused by a great increase of temperature. Such assistance is desirable in case of a single-track bridge, when care must be had to provide enough safeguards to maintain lateral stiffness and to prevent the structure from getting out of line. The great tendency of the cables to assume a vertical plane will of course contribute very much to the horizontal stability of the arches, but it is still advisable to avail ourselves of such a cheap and effective auxiliary as will be provided by these under-floor stays. Their tension should be adjusted so that a maximum contraction in the winter caused by their own shrinkage and the shortening of the superstructure will not overtax their strength. But it will be observed that the tighter they are the more power they will possess to pull the structure back, when an increase of temperature occurs. On that side of the main span, where its whole length, together with one side span, expands and contracts in one, still longer stays may be applied, if it should be found desirable, and also heavy weights suspended to it to give them more deflection without an increase of tension, and thus to render them more efficient and safe in the performance of their task.

The ends of the trusses are further secured vertically, as well as laterally, by two wire-ropes, one on each side of the structure, anchored to the pier by joints, which will admit freely of the movement of the upper ends, where they are fastened to the top chords, in accordance with the contraction and expansion of the structure.

*Statical Condition of the Structure under the Action of variable Loads.*—Suppose a maximum transitory weight of 750 tons evenly distributed over the whole length of the central span, and no loads upon the side spans, what will be the statical condition?

The following Table exhibits the relative portions of weight borne by the stays, the cables, and the arches of the central span when taxed with a maximum load, including superstructure.

| | Weight of Superstructure. | Transitory Load. | Total Weight. |
|---|---|---|---|
| | tons. | tons. | tons. |
| Borne by stays .. .. | 150 | 174 | 324 |
| „ cables .. .. | 290 | 336 | 626 |
| „ arches .. .. | 210 | 240 | 450 |
| Total .. .. | 650 | 750 | 1400 |

We will first consider the action of the stays. This action is twofold: first they exert a force upon the top of the tower, which may be resolved in a horizontal and vertical direction, and will be fully considered hereafter. Secondly, their force produces a horizontal tension as well as compression upon the lower chords. Now, as there is a system of stays on each side of the tower, if their horizontal action is the same, the compression of the chords on the one side will be met by the compression on the other side, and there will be equilibrium. But if the side span is relieved of its transient load, while the main span remains loaded, then the equilibrium between the opposite stays will be disturbed. The tension of the stays on the side span being relieved, the top of the tower will slightly yield toward the main span, as far as will be permitted by its inherent elasticity and stiffness. This will partially restore the lost tension of the stays, and the horizontal compression of the chords will remain nearly the same. No other change can result, because the stability of the towers will be maintained by the leverage of the side span, as will appear hereafter.

Next, let us consider the condition of the central arches, under a pressure of 240 tons produced by the transitory load, without any corresponding weight upon the arches of the side spans. The compression at the foot of the arches, caused by the above weight, is $240 \times 1{\cdot}7 = 408$ tons, and the horizontal thrust, Fig. 1432, $408 \times \frac{258}{270} = 390$ tons.

The ends of the arches being connected by the lower chords and framing of the floor, these parts will be exposed to this thrust most directly. Allowing 5 tons maximum tension a sq. in., a section of $\frac{390}{5} = 78$ sq. in. will be required. Now the lower chords are composed of eight channel-bars of 7½ sq. in. section each, making 60 sq. in. Add the sections of the 9″ girders, underneath the tracks, which are brought into full action by the braces at the towers, 18 sq. in. Total, 78 sq. in.

The excess of pressure of the central arches is therefore fully met. But the three spans form one continuous truss, and consequently a great resistance will also be offered by the upper chords and by the inherent stiffness of the whole structure. It is therefore plain, that so far as the arches are concerned, their stability and safety under the action of the heaviest transitory loads are sufficiently secured.

It remains now to examine the conditions brought about by the united action of the cables and stays when taxed by a maximum load in the main span, without corresponding loads in the side spans.

| | Tons |
|---|---|
| The weight upon the cables caused by this load is found in the above Table .. | 336 |
| And the tension at the top of towers, $336 \times 1{\cdot}22$ .. .. .. .. .. .. .. | 410 |
| The horizontal force acting at the saddle is found to be, Fig. 1433, $410 \times \frac{265}{291} =$ | 373 |
| Add to this the horizontal force produced by 12 stays .. .. .. .. .. .. | 165 |
| Total .. .. .. .. .. .. .. .. .. .. .. .. .. | 538 |

Now this combined force acts upon the top of the towers, its height serving as a lever, with a tendency to lift the adjoining side span. The moment of this force, therefore, is $538 \times 62 = 33356$.

The weight of superstructure of the middle span was assumed at 650 tons, or per foot lineal $\frac{650}{500} = 1{\cdot}3$ ton. The weight of the side span per foot lineal is about 1·2 ton. The length of the side span is 327 feet. Consequently its total weight, $327 \times 1{\cdot}2 = 392{\cdot}4$ tons.

This weight may now be supposed as acting at the centre of the span, and the leverage of its action in maintaining the stability of the whole, is equal to half the length of the span; consequently the moment of force is $392{\cdot}4 \times 163{\cdot}5 = 64157$.

But the end of the side span is held down and kept from rising by the stays underneath the floor and by the two powerful wire-rope braces which secure their lateral position. These combined resistances may be estimated at least at 100 tons, and this force acts with a leverage equal to the whole length of the side span; consequently its moment is $327 \times 100 = 32700$.

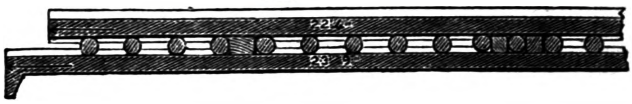
Total moment, 93,857, or nearly three times as much as is needed to maintain an equilibrium.

The above investigations authorize the conclusion that this Parabolic Truss is not only amply strong in all its different parts when uniformly loaded, but that its safety and stability are also amply provided for under the variable action of maximum loads. Indeed, when comparing the rates of allowances made in this plan, with those usually observed with iron railway-bridges in this country, where cast iron is so abundantly made use of, it would almost appear there is an unnecessary strength provided for.

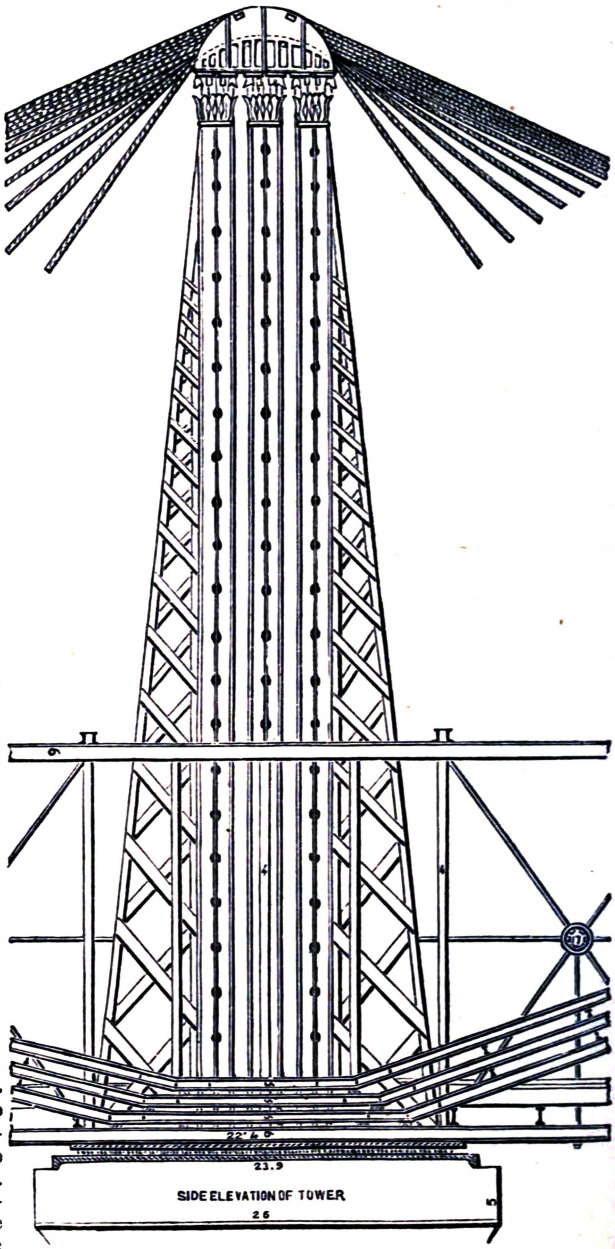
*Roller-plates.*—The whole length of parabolic superstructure is 1184 ft., and forms one single continuous truss, whose integrity and continuity must not be interfered with in any way whatever. Hence the great importance of providing for efficient means to facilitate the free contraction and expansion of the work in consequence of changes of temperature. The superstructure is permanently fastened and anchored upon one of the middle piers, and from this fixed point the side span adjoining is allowed to expand and contract. A roller-frame is therefore placed upon the abutment, or upon the pier, which serves as such. On the opposite side, the middle span together with the side span contracts and expands as one and consequently roller-frames are placed upon the second middle pier, as well as upon the abutment.

No strife or interference between the different parts of the structure can take place while this process of contraction and expansion is going on, because all parts are made of the same kind of material—wrought iron — and therefore the arches, cables, chords, and towers will go and come in the same relative ratio. When the temperature increases, the chords, arches, and cables will increase their length, and the whole structure will be lengthened out. The panel or truss posts will increase their length: in the same ratio the arches will rise and the

1435.



1436.

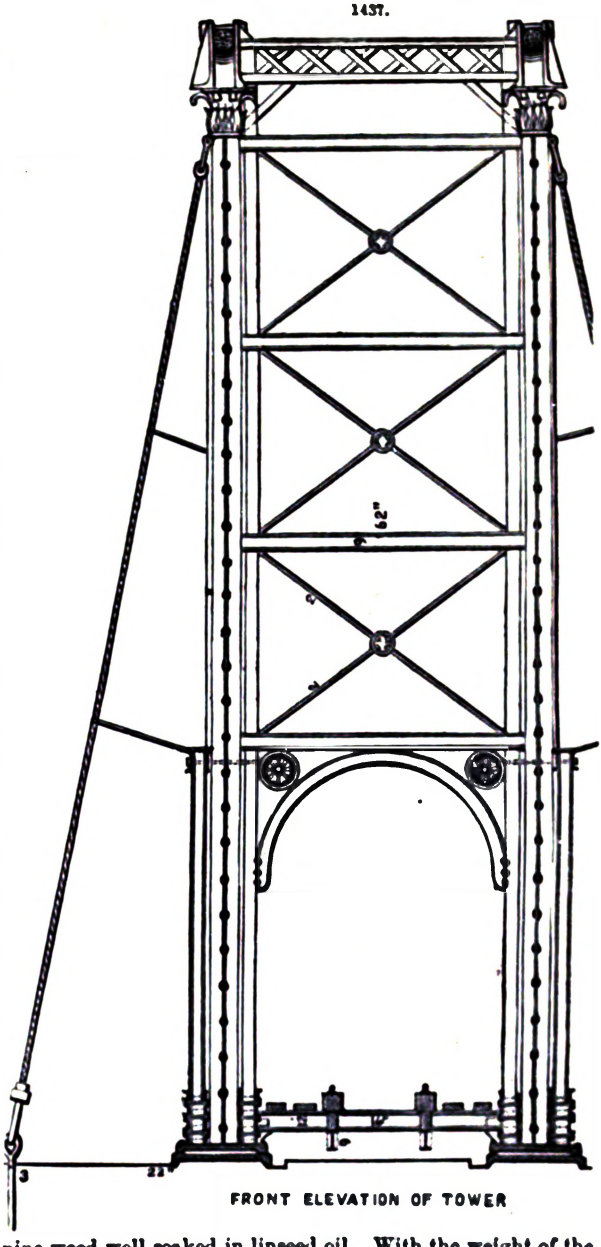


cables will sink, preserving a uniform tension among the suspenders and panel-rods. At the same time the towers will raise their heads and compensate for the increased length of cables and stays. The whole truss may be considered as fastened to one metallic sheet in a vertical position, expanding or contracting in all directions.

A bar of wrought iron 150,000 ft. in length will expand or contract 1 ft. for every degree of change. Now assuming the extremes of temperature at 150°, the extreme limit of contraction and expansion of one middle and side span, which measures 857 ft. in length, will be 0·857 ft. The roller-plates on that abutment must therefore allow of this much play. Whether the temperature of the iron rises to 120° in a July sun, or falls to 30° below zero in the dead of winter, we are sure that all parts of the structure will freely accommodate themselves to these changes, and will never fail on that account to support their allotted parts.

An inspection of the cross and longitudinal section of roller-plates, Fig. 1435, will make their simple construction perfectly plain. Both the upper and lower plates are of cast iron; the rollers between are of wrought iron. The inner faces of the plates must be planed off true, so that the bearing of the rollers, which are all turned off to the same diameter, will be even and uniform. It is customary to connect the rollers by a frame; but this is an unnecessary expense and no improvement. The edges of the rollers are slightly rounded off, say $\frac{1}{8}$ in., and the plates confine the rollers between flanges 1 in. deep. These flanges are sloped $\frac{1}{8}$ in., which prevents friction between them and the rollers. At the same time the slope is too steep to admit of the mounting upon it of the edges of the rollers. To ensure parallelism between the rollers, they are placed together where the pressure is very great, and where the pressure is light, as in the case before us, they are spaced by inserting between them strips of seasoned pine-wood well soaked in linseed oil. With the weight of the structure upon the plates the rollers will keep their relative positions. It is easier and cheaper to ensure parallelism on this plan than by the employment of roller-frames. Steel rollers are sometimes used in place of iron rollers. But this is objectionable in connection with cast-iron plates. The rollers on the towers of the Niagara Bridge are made of cannon-metal, and are 5 in. in diameter. When steel is used for rollers, both plates should be faced with steel; if not, then the hard rollers will make an impression on the softer cast iron.

1437.



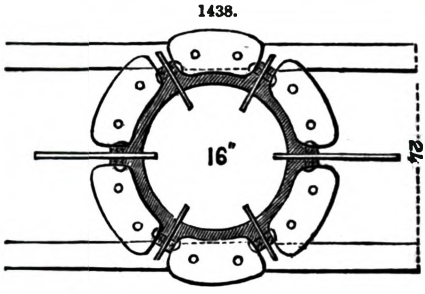

FRONT ELEVATION OF TOWER

The rollers exhibited, Fig. 1435, are 4' 4" long and 3" in diameter. The plates are 3" thick. The lower plate is well settled on a heavy bed of rich cement-mortar. The wooden strips between the rollers are not represented on the plates which support the tower, Figs. 1436, 1437.

*Towers.*—The towers are 62 ft. high above the roller-plates. Each tower, Figs. 1436, 1437, is composed of two shafts, which form parts of the trusses, and are firmly connected with the chords and arches. Each of the shafts is composed of three columns, and each column again may be constructed either of four, six, or eight sections. Fig. 1438 exhibits a section of a column composed of six segments. In Figs. 1436, 1437, the columns are drawn with four segments only. The interior circle of the column is assumed at 16 in. The shafts being 59' 2" high from the roller-plate to the saddle, the sections may be rolled about 20 or 30 ft. long, so as to break joints. Every joint must be covered by a splicing-plate inside. The intermediate plates which connect the

segments, also breaking joints with them, will likewise add to the firmness of the columns. Both ends of the columns are to be planed off true, and so must be the end of every intermediate piece, so that every joint will make a tight fit. The respective columns of the opposite shafts are connected horizontally by a system of channel-bars and diagonals, which will fully ensure their lateral security. This is further increased by two lattice-beams, which connect the cast-iron saddles, as is plainly exhibited in Fig. 1437. The top roller-plate being planed off on both sides, the lower ends of the columns will have a fair level seat upon them. The shafts are thus enclosed between the foot of the arches and the lower chords, and firmly connected with them laterally by flat bars, angle-irons, and stay-bolts. When the flanges of the inner channel-bars and those of the columns meet and interfere with each other, they are cut away for a few inches. The truss-posts at the towers are also firmly connected with the shafts, and so are the upper chords, and these connections will add much to the strength of the structure. In the direction of the trusses each tower is further secured by four lattice-braces which run between the chords and arches. The stability of the towers in this direction is also increased by the stays, and in a lateral direction two powerful wire-rope guys add to their security. These guys serve as anchors, and being hinged at the lower ends, will not interfere with the free contraction and expansion of the structure. To guard against lateral vibration of the lattice-braces, their outer chords are strengthened by plates 12 in. wide and ½ in. thick, riveted to a heavy T-bar which connects with the lattice-bars, Figs. 1560 to 1563.

1438.




It will be noticed that the towers, forming one connected whole with the trusses and arches, will move freely on the roller-plates along with the rest when affected by contraction and expansion on that pier which is provided with rollers. On the other piers the towers are stationary.

The greatest vertical pressure upon one tower (two shafts) is equal to 950 tons. Allowing 4 tons maximum compression for 1 sq. in. section of iron, we should require $\frac{950}{4} = 237\frac{1}{2}$ sq. in., or $118\frac{3}{4}$ sq. in. in each shaft. In place of this, we have allowed a section of 150 sq. in., which reduces the pressure upon each superficial inch to 3·16 tons at the top of the tower. As we descend, the strength increases considerably by aid of the lattice, and when the upper chords are reached the strength is nearly doubled. We are therefore sure that ample allowance is made for the supporting power of the towers.

*Saddles.*—The saddles on top of the towers are of cast iron, 8 ft. long by 3 ft. 6 in. wide at the bottom plate. The construction is given in Figs. 1436, 1437. The lower face is planed off, so that when the top of the columns is brought to a level, the two surfaces will have a fair and equal bearing. In order now to secure the saddle horizontally, six small segmental plates are fitted around each column, and secured to the bottom of the saddle by set screws. To do this, an exact template should be formed of the top of the shaft, before the saddle is hoisted; then the holes may be marked off for the set screws, and sunk into the saddle: the small plates can then be screwed on to its lower side before the saddle is finally put in place.

The inside section of the saddle is so shaped that the wire-ropes for supporting the cables and stays will occupy their relative positions. Four ropes are placed in the bottom row; they, together with the two outside ropes of the next tier, compose the six stays. The next three middle ropes, the second tiers, form the lowest layer of the cable.

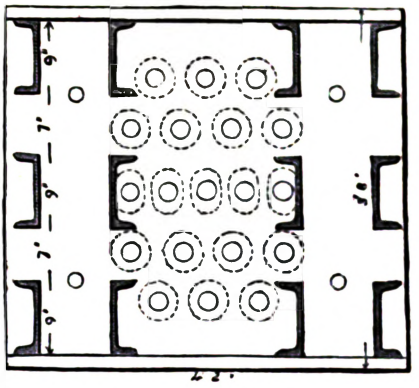
Two forged pieces of wrought iron 4″ × 6″, with triangular pieces underneath, are let into the four notches of the sides of the saddle and screwed down for the purpose of securing the cables and to prevent sliding. This being done, the cables and tower now form one. When there is a greater strain on one side than on the other, the elasticity of the tower will admit of sufficient yield to equalize the difference.

*Anchor-plates.*—The end of each cable is secured to a cast-iron plate, which at the same time serves for the arch to butt against, and thus the two are made to balance each other. Figs. 1439 to 1441 exhibit views of both faces of the plate, and also a section in which the fastening of the ends of the wire-ropes is made clear. The dimensions of the plates are 4′ 2″ × 3′ 8″, with a thickness of metal of 8″ in the centre and 3″ around the sides, strengthened by ribs. A cable being composed of nineteen ropes or smaller cables (twisted or not), there are nineteen corresponding holes for their reception. These holes are conically shaped, the larger opening having twice the diameter of the smaller one. Some of the large openings are elliptically shaped, in order to gain room. That face which serves as an abutment for the channel-bars, composing the arch, is to be planed off to admit of a fair bearing. The weight of the plate is supported by its upper flange, which rests upon the ends of the upper channel-bars. A further support is provided by two cast-iron posts which fit against the face of the end truss-posts and are bolted to it. It remains now to convey a clear idea of the manner of securing the ends of the small cables within the plate. This is done by spreading apart the different wire-strands and wires which compose a rope, and inserting a number of iron points between them in such a manner that the whole span inside of the conical hole is filled out solid, Fig. 1440. By these means the end of the rope is swelled out into a conical lump 8 in. long, which cannot slip out of the plate without bursting it.

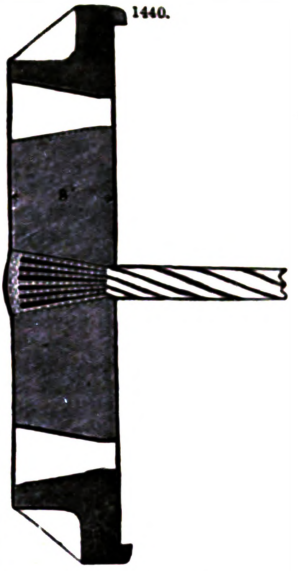
It is important that these plates should be cast of the strongest metal—good, strong, cold-blast charcoal metal—such as is used for the manufacture of good car-wheels. The points driven in between the wires may vary in length as well as in thickness. First drive in a number of long ones, 6 to 8 in. in length, about ½ in. in diameter at the thick end and gradually reduced to a point, filed off round and dipped in linseed oil before driving, to make them go easy. Also pour

some linseed oil between the wires, to make them smooth. The oil will prevent the staving up of the wires and facilitate the process. After filling up the remaining spaces with shorter and thinner points, then cut off the ends of the wires projecting over the plate even with it, one after another, and bend their ends to a right angle over the ends of the points. This being accomplished, apply a clay mould around the whole, so as to form a raised rim, and pour in melted lead, which will fill all the remaining interstices and make the whole one compact mass. After removal of the mould apply the hammer to make the lead solid, file it smooth, and round it off a little to give it a finish. To insert the ends of the ropes without trouble, it is necessary to wrap them well with annealed wire, and as the end is forced in, the wrappings will be pushed back.

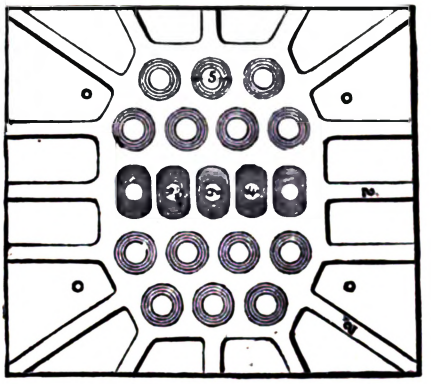
1439.



1440.



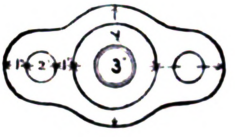
1441.



*Stays.*—Similar to the plan just described is the method of fastening the ends of the stays: with this difference — that each stay-rope has a cast-iron socket for itself. This socket, together with the wrought-iron stirrup which holds it, is represented by Figs. 1442 to 1445. The stirrup is made of round iron $1\frac{1}{8}$" diameter, and varies in length to suit the inclination of the stay. Where the stirrup passes around the floor-beam, a small segmental casting, forming a seat for the stirrup, is fitted against the beam, for the purpose of giving the stirrup a fair bearing. The screws must be long enough to tighten the stays. To preserve their straight lines, they are connected with the suspenders by wire wrappings.

1444.

1442.



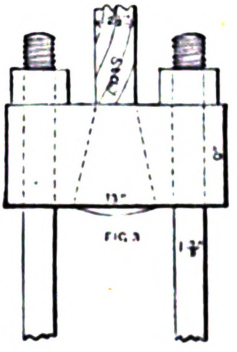
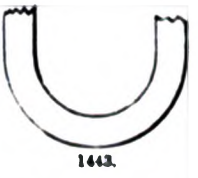


FIG. 3



1443.

1445.

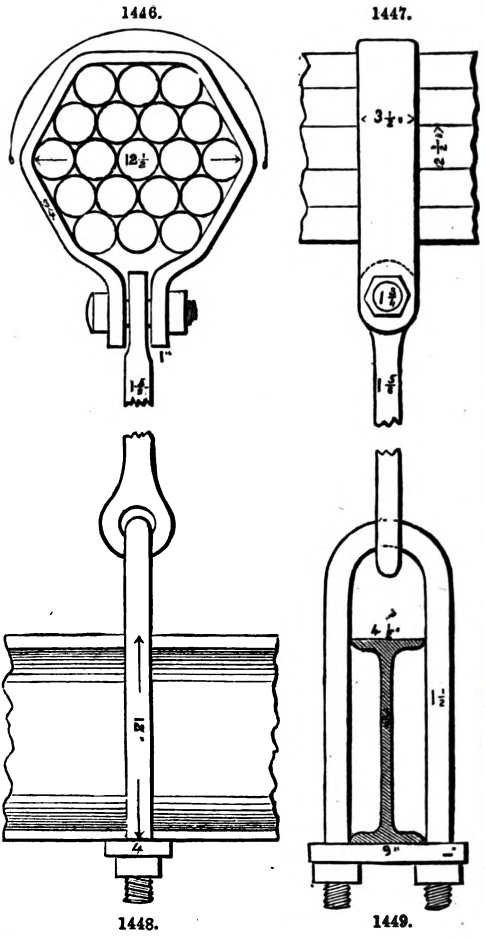
It will be noticed that the stays as well as suspenders, together with the cables, are all suspended in one vertical plane which passes through the centre of the 2-ft. space left open between the two rows of truss-posts. The cross-bars connecting each pair of posts are not to be put up until the stays, cables, and suspenders have been placed and fixed in their position.

At the ends of the trusses four small stays may be noticed, which are provided for the purpose of guarding against vibrations at those points, and also to add to the supporting strength. The upper and lower chords being necessary, independent of support: their strength is thereby brought into play. Accordingly as much tension is thrown upon the stay-ropes as the resistance of the chords will permit. The ropes are double, and their diameter varies from 1 to 2 in.

*Cables.*—There are two wire-cables, one on each side, suspended in vertical planes between the double rows of truss-posts. Each cable is composed of 19 wire-ropes of $2\frac{1}{2}$ in. diameter. The maximum tension of the two cables at the tower is 764 tons, and at the centre of the main span 696 tons. Dividing 764 by 36, we have the tension of each rope equal to $20\frac{1}{19}$ tons: and, allowing

six times the strength, we have for the ultimate strength of each rope 120·6 tons. Although the tension of the cables is less in the centre, the same section and strength are observed throughout. A chain may be tapered, but it would be false economy to attempt it in a cable. Fig. 1446 shows a section of one cable on a larger scale. The nineteen ropes are suspended in five layers, and care must be had to preserve the relative position of each layer, as well as of each individual rope, throughout its length, so that the union of the whole nineteen will in section form a hexagon. The suspenders being attached every 10 ft., a strap is laid around the cable, and screwed up tight, to preserve its form. These straps should be made by about three different patterns, to suit the inclination of the different parts of the cables. When putting them on, they are heated in a small hand-forge, and a strip of sheet iron is laid over the cable to prevent heating the wire. After closing, they are cooled by pouring on water.

To keep snow and wet out of the cables, they should be protected by a half-circular cover made of tin, secured to the straps by small wire wrappings. This is indicated in Figs. 1446 to 1449.




A uniform tension of the ropes is easily obtained by suspending them parallel to each other in level layers, and in close contact. First secure one end in the anchor-plate; then adjust the rope in the saddles with a proper deflection at the lowest point of each span. Then pass the other end through the other plate, open the seven strands, and pass the centre one through a conical tube 7 in. long, wide enough at the small end to admit the strand, and at the other end enlarged to double the diameter. The whole rope being a little longer than necessary, say 1 to 2 ft., the centre may be fastened temporarily or anchored back, preserving at the same time its central position in the hole. By slackening or tightening this centre now, the position of the rope in the cable may be adjusted. When right, drive the hollow tube into the anchor-plate some distance, and at the same time insert a number of large points, and drive them all in uniformly. When all the large pins are in, the centre may be released, and the untwisted wires may be cut off the right length. Then insert thinner points in the centre tube, and fill it, and complete the whole. To give a support to the anchor-plate, it is of course necessary to put up the truss-posts as far as they rest on the abutment, and to secure them temporarily by timber-bracing. And it will also be necessary to provide for a temporary anchorage of the anchor-plate itself before the arches are put up. This may be done by extending a few wire-ropes from the anchor-plate and posts to the next pier or abutment, and secure them; and if this masonry is not strong enough, a temporary anchorage of timber and stone must be put on shore, of sufficient strength to resist the pull of the cables. The same wire-ropes which are to be used for the abutment-stays and for the storm-cables, and which are to be delivered in long coils, may be advantageously used for this temporary anchorage with very little loss or waste.

The tension of each full cable, resulting from their weight when freely suspended, will be 63 tons; and this has to be fully met and supported. By the use of a few railroad bars laid across the posts above and below the anchor-plates, and by passing stirrups or chains around them, the anchor-ropes may be attached. On the shore they may be fastened to similar bars, placed in an excavation, the bars to be secured to a rough framework of timber and plank, and this may be kept in its place by earth, gravel, stone, and other heavy material; it may also be assisted by braces. Piles may also be driven to increase the resistance of this temporary anchorage.

In order to put up the arches and other parts of the superstructure, a temporary platform and footway will have to be suspended. As to the cables, a light foot-bridge under each will be all-sufficient, and the same anchorage which answers for the main cables will answer for the foot-bridge cables. It should be observed here, that the temporary anchorage should be made strong enough to resist a pressure of about 400 tons, because this much tension may be produced by the cables while erecting the superstructure.

While putting the ropes in the cables, they should receive another coat of durable paint. Allowance must be made for the stretch of the cables. All wire will stretch, whether made of steel or iron. A No. 8 steel wire of good quality, capable of supporting a weight of 3000 to 3400 lbs., and 5 ft. long, will stretch 1 in. before breaking. After being taxed with a full load for some time, the stretch of the cables will cease, because the material will have assumed a permanent set. After this, no more elongation will take place. The deflection of the cables in the main span, after the

wire has attained a permanent set, is to be 60 ft. An allowance of 1 to 2 ft. should be made for settlement. If the cables are well made, 1 ft. will be enough; but if poorly made, 3 ft. may not be sufficient. To be more explicit, the cables should be suspended with a deflection of, say 58 ft., if well made, and if not, 56 to 57 ft. will be safer.

In order to make the cables bear their allotted portion, the suspenders have to be screwed up repeatedly after full trains have passed over the work. The permanent set of the cables will make itself felt distinctly if attention be paid to it. On the other hand, it would be wrong to tax them too much, and thereby relieve the arches to an undue degree. A proper adjustment may at first sight appear to be impossible, or at any rate attended with great difficulty. But if the directions given here are strictly carried out, this adjustment may be readily accomplished.

The weight of the superstructure which is to be borne by the cables of the main span is 290 tons. The number of suspenders is 96, and therefore the weight borne by each is $\frac{290}{96} = 3{\cdot}02$ tons. Each suspender being attached to a stirrup which has two screws, the weights to be borne by each single screw will be 1½ ton, or 3000 lbs. Now practise a few intelligent men in raising a weight of 3000 lbs. by such a screw, using a screw-wrench of a certain length, say 18 in. The screws should be well cut, so as to run easy and smooth. No stirrup should go into the work without having the screws well examined, well cleaned, run smooth, and oiled.

The handles of the wrenches should be just long enough to require the average strength of a man's arm. To make this operation still more certain, the wrench may be tested by a suspended weight, so that the men can compare their strength with the actual weight. Much depends upon the cut of the screws; with good uniform threads, every suspender must be brought to a fair and equal bearing.

The length of the suspenders being calculated, they are manufactured accordingly, and put in place; but the theoretical length will never exactly agree with the actual length, and the difference is made up by screwing. The above remarks on suspenders will equally apply to the stays. The ultimate strength of each stay is 100 tons, and they are calculated to bear an ultimate tension of ⅕, or 20 tons, caused by the superstructure and a maximum load. Now, the proportion of weight of superstructure to that of maximum load which falls upon the stays is as 150 : 174, as will be seen in the Table of relative loads; consequently they may be screwed up to a tension of about 9 tons, and this is accomplished with a wrench of about 3½ to 4 ft. long.

After the cables have obtained their permanent set, and the suspenders and stays have been adjusted, no more attention need be paid to this part of the structure. The relative supporting power of the cables, stays, and arches will remain unaltered, they will not undergo any further change. And as changes of temperature will influence the aches as well as the cables alike, no strife between the different members can arise on that account.

The curve formed by a cable when freely suspended and not loaded, will be that of a catenary, because the weight of a unit of cable is supposed to be the same throughout its length. But with a weighty horizontal platform suspended to the cables their curve is changed, and will be found to correspond more to a parabola than to a catenary. The suspenders may accordingly be calculated for a parabola, but it will be found in practice that they vary, and sometimes considerably, from both curves. The screws at the ends of the suspenders will be the means of adjustment. But another change in the curvature of the cables will take place when the stays are tightened and begin to relieve the cables at those points. They will then be lowered in the centre and raised near the towers. Allowance must be made for this in the length of the suspenders, so far as the stays extend.

*Suspenders.*—The maximum weight borne by the 96 suspenders of the middle span is 626 tons. Each suspender, therefore, has to support $6\frac{13}{100}$ tons. Allowing seven times the strength, we want for the wire-rope suspenders an ultimate strength of 45 tons, or 1¼" diameter rope.

Figs. 1444, 1445, show a wire-rope suspender, both ends fastened in wrought-iron sockets, and the lower socket attached to a stirrup which passes around the floor-beam. Figs. 1447 to 1449 exhibit one of the short, solid suspenders hung to the cable-strap and to the stirrup below. The rods are 1¼" diameter, and the stirrups 1½" diameter. These dimensions may appear extravagant, but when it is considered that under a heavy passing load, every single suspender is taxed more than its general proportion, this large allowance will be justified.

*Chords.*—The arrangement of the upper and lower chords is plainly exhibited on the plans. Figs. 1436, 1437, show it more particularly. The 9-in. channel-bars composing them extend from end to end without interruption. The lower chords are not plated underneath at any point. This is not wanted on account of strength, and their lateral stiffness is amply ensured by the floor-beams, by the plates to which the tie-rods are secured, and by the stay-bolts. Nor are the upper chords plated on top, except in the side spans from the end of the truss to the point where the cable enters. These top plates are ½ in. thick and 50 in. wide. The cross-beams are here placed on top of these plates and riveted to it.

The splicing of the chords is done in the same manner as that of the arches. Whenever a stay-bolt is applied to the chords it is passed through a gas-tube, which is cut off on the lathe to the right length, and thus a firm and simple connection is made. In order to meet the thrust of the arches, in excess in the one span, while no load is on the other, a section of 60 sq. in. was found to be necessary for the lower chords. The horizontal action of the stays at the tower is compressional only, and does not add to the tensile strength of the arches. The horizontal action upon the chords, which results from the diagonal rods in the panels, is balanced in each panel, and requires therefore but little section.

A section of 6 sq. in. for the channel-bars of the upper chords will be an ample allowance. The same section may be observed throughout the length of chord. It is, however, necessary to make the splices of the lower chords as strong as the channel-bars themselves, so that they may

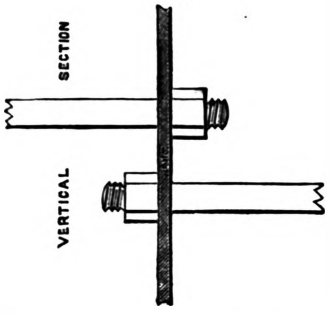
resist a full tensile strain, which may be brought upon them by the arches when the spans are unequally loaded.

*Posts.*—The posts are of the beam section, and 9 in. wide or deep; Figs. 1450. 1451, exhibit sections on a larger scale: the weight is 25 lbs. a foot. All the posts are 22 ft. long, except those in the centre span, which vary from 22 to 44 ft.

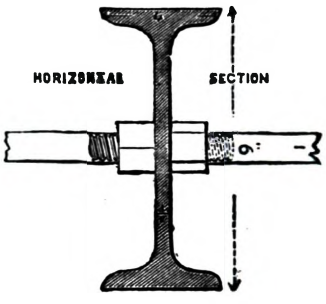
Each truss consists of two rows of posts planted 24 in. apart, in which open spaces the cables, stays, and suspenders are freely suspended. They are firmly connected by horizontal bars $1\frac{3}{4}$ in. square: the ends of these bars are spread out so that they will give room for 4 rivets of $\frac{3}{4}$ in. diameter, to be fastened upon the flanges of the posts. Each cross-bar is therefore held by 8 rivets.

In order to increase the lateral stiffness and stability of the trusses, the intervening space between the posts may be enlarged to 30 or 36 in.; and the connecting-bars should then be 2 in. in place of $1\frac{3}{4}$ square. The vertical stiffness of the posts in the direction of the trusses is aided by horizontal connecting-bars at the centre. These bars are only 1 in. diameter, pass through the web of the posts, and are simply screwed up by a nut at the end, as is shown, Figs. 1450, 1451,

1450.




1451.




1452.

By tightening these bars uniformly, the lateral position of the posts is secured and vibration prevented. This provision is very necessary, on account of the great length of the posts.

*Arches.*—The arches are formed of channel-bars, Fig. 1452. The posts being 20 ft. apart, the channel-bars are rolled of the same length so that the splices all come upon the posts. It will be noticed that the connections with the splicing-plates are made with screw-bolts, and not with rivets. This will greatly facilitate the putting up and adjustment of the arches. One of the practical difficulties in putting up such work is to make the ends meet, and to make a tight and workmanlike fit, so important in arches and chords. This difficulty is much increased by great variations of temperature, and hence the importance of using screw-bolts in place of rivets. The bars may at first be put together loosely and without any tight fit, by using small bolts temporarily, which are to be removed after the joints are brought to a close. Each pair of splicing-plates, opposite each other, is connected by six bolts of $\frac{7}{8}$ in. diameter, or three on each side of a post; on being drawn tight, they embrace them solid and firm. In order to screw these up tight, they must not be enclosed in tubes. The remaining four bolts, on the other hand, are passed through gas-tubes 9 in. long and 1 in. wide, which therefore preserve the distance between the channels and serve as stay-bolts. Two small plates 4 in. × 7 in. × $\frac{1}{2}$ in. thick are riveted to the post and fitted between the channels. Two of the channels are therefore firmly enclosed between these plates and the brackets. To add still further to the stiffness of the splices, the cross-channels which connect the two lines of trusses are filled in between and firmly bolted to the posts, while at the same time their flanges are riveted to the flanges of the arches. When the latter cross the posts obliquely, the cross-channels have to be heated and swedged in a block by pressure, so as to fit the oblique section. By using wedges of different shapes to correspond to the inclination of the arch, one press or one pair of blocks or dies will do for the whole. If the cost of such a press is objected to, the flanges of the cross-channels may be cut out and the stem only bolted to the post.

So far as the arches rise above the upper chords in the central span, the upper channels are connected by a top-plate of $\frac{1}{4}$ in. thick riveted to the upper flanges. Laterally, between the posts in each panel, the arches are again connected by four channels of 50 in. length each, and also by stay-bolts passing through gas-tubes.

Where the arches rise above the upper chords, the channels forming the latter are cut out and planed off to the proper level to make a good fit. Splicing-plates are then riveted over the joint, and the respective flanges are also connected by rivets. At the same time a plate of 4 ft. long by 2 ft. wide and $\frac{1}{4}$ in. thick is riveted down on top, so as to cover all the joints. The depth of each arch is 41 in., and its width 4 ft.

Considered as a straight girder freely spanning a distance of 60 ft., this combination would be stiff enough for railroad traffic. But its inherent stiffness is not calculated to serve as a supporting power, but to resist lateral deflection like a column. A round column is, of course, the best geometrical section for gaining lateral strength. But a columnar section in wrought iron for the purposes of an arch, presents many difficulties and objections. What would be gained in section would be more than lost in reduced strength of framing.

The great facilities of construction which the plan before us offers, must not be underrated. And when we consider the small section of wrought iron that is needed to make the arches effective, this plan will compare favourably with other plans heretofore attempted. The arches

of the Coblenz Bridge over the Rhine are 308 ft. wide in the clear. Each rib is 10 ft. 6 in. deep, with upper and lower flanges. The flanges of the centre rib are 3 ft. 2 in., and those of the outer ribs 2 ft. 2 in. wide. These arched ribs have been treated as flexible trusses, consequently the upper and lower flanges have been graduated like chords, with the greatest section in the centre. The upper and lower chords are connected by posts and diagonal braces. This work is considered a model work; it is well proportioned and possesses ample strength. The stiffness is in the arches alone, and no attempt has been made to increase it by spandril-bracing. Its rigidity is owing, in a great measure, to the placing of the floor *below* the crown of the arch.

The question arises, whether flanged arches with greater inherent stiffness would not be better adapted to the Parabolic Truss, than the arches here designed? So far as simple supporting power is considered, under the action of uniformly-distributed loads there would be no difference between the two plans. As regards stiffness, under the action of variable loads, however, the plan here proposed, with its great depth of trussing, will produce more rigidity, with the same amount of material expended, than would result from flanged arches. This view will apply with still greater force, when the arch descends below the lower chords. The depth of ribs in the Coblenz Bridge is 10 ft. 6 in., and the clear span 308 ft. (Prussian measure), a proportion of about 1 in 30. This depth would evidently be entirely too small for a straight girder of 308 ft. span, but it would be enough for a span of 100 ft.

In the Coblenz Bridge, the floor intersects the girders or ribs at the lower chord, and we may therefore consider the whole arch, so far as stiffness is concerned, as divided into three equal parts. The central part is stiffened by the floor, and the spandrils are stiffened by the posts which support the floor. But no further bracing has been attempted in the spandrils, on account of contraction and expansion; but this appears to be a defect, because an expenditure of very little additional material would have greatly added to the rigidity and strength of the work without materially interfering with contraction and expansion. It must be remarked, however, that the leading idea in the design of this celebrated viaduct was to interfere with the arches as little as possible, and to depend upon their own inherent stiffness, so that the ribs should be at liberty to accommodate themselves freely to variations of temperature. This same view led to the planning of the *pivot* skewbacks; but this defect has been corrected since by making the bearings of the skewbacks all solid.

When we omit the arches in our plan, considering the structure as a pure suspension-bridge and compare its stiffness with that of the Niagara Bridge, we discover that the truss here designed possesses ample stiffness for all railroad purposes. The Niagara trusses are only 18 ft. high; those before us are 22 ft., with a span of 500 ft.; while the Niagara span is over 800. In the Niagara Bridge the truss-posts are 6 ft. apart; here they are 20 ft. The Parabolic Trusses being double, there are four diagonal rods of 1¼ in. diameter in a panel of 20 ft., while there are two rods of 1¼ in. in a panel of 5 ft. at Niagara. On the other hand again, the Parabolic Trusses are all of iron and have comparatively very strong chords, while the Niagara framing is of wood, with light chords, which are, however, very materially assisted by the floors and the central girders, which latter distribute the weight of concentrated loads.

Roebling concludes that the trusses before us (without including the feature of the arch), will be quite as stiff as are the Niagara trusses.

When compressive action takes place in chords and arches, experience has demonstrated that 4 tons of 2000 lbs. each, or 8000 lbs. a sq. in. maximum pressure, is as much as soft, puddled iron should ever be taxed. But this resistance depends so much upon lateral conditions that the above allowance of 4 tons would scarcely be safe for single arches *not* assisted by cables. But the great feature of safety in the Parabolic Truss is the cable. The arch is only an auxiliary to the cable. With ordinary loads, the cables and stays will support the greatest part of the strains; and the more they are strained the greater their tendency to maintain their vertical positions, and to assist the arches in preserving their true alignment. *Lateral flexure is the great danger to arches.* The more jointed and articulated the system is, the greater this danger. Now, these considerations must be taken into view when deciding upon the choice of material for the arches. The question of steel or iron is of course a question of comparative estimate. But if, for instance, we allow 8000 lbs. maximum compression for iron, and 12,000 lbs. for a mild steel, and the steel arch costs the same as the iron arch, both possessing the same supporting strength, then the iron arch should be preferred to the steel arch, for the following reasons:—

1. The greater section of the iron arch will ensure greater lateral stiffness than can be obtained from the diminished section of soft steel.

2. The greater weight of the iron structure adds to its stability under the action of variable loads in direct proportion to its superior weight when compared with steel. Vibrations caused by fast-moving trains will be felt more by the lighter structure than by the heavier one.

One of the best features of the Parabolic Truss, as here designed, is, that the principal members of this system are nearly uniform in their sections, and that they are not alternately exposed to such opposite strains as compression and tension in succession.

The cables and stays experience tensile strains only, while the arches are exposed to compressive action alone. This feature will add much to the lifetime of the structure.

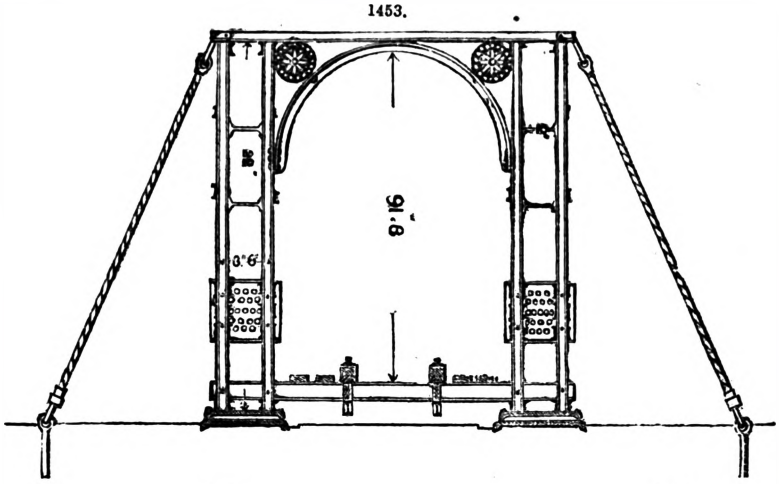
An objection may be raised to the parabolic form of the arches, because of the variation of bevels at the joints. The difference, however, between the segment of a circle and the parabolic curve, with the proportions here observed, is so small, that the substitution of the one for the other will not have the slightest practical influence. It will therefore facilitate the work, to cut all the joints to the same bevel for a circular arch. Respecting the cables, however, the suspenders should be calculated for a parabolic curve.

*Floor-beams.*—The beams supporting the railroad track are 5 ft. apart and 12 in. deep, and weigh 40 lbs. a lineal foot. If manufactured of good iron, a load of 23 tons, equally distributed, will not produce a sensible deflection, and a load of 15 tons on the two rails will be within its elastic limit. The lower flange of each beam is riveted to the upper flanges of the channel-bars com-

posing the chords, sixteen rivets of $\frac{5}{8}$ in. diameter for each beam. This forms a very stiff horizontal connection of the opposite chords, and renders all further diagonal bracing unnecessary. This stiffness is further increased by the 9-in. girders, running lengthways underneath, riveted to the beams, and connected with the timber stringers, the rails, and the breachings by stirrups 2 ft. 6 in. apart.

The upper joints, connecting the arches and upper chords, are channels 7 in. depth, of a light section, one on each side of a post bolted to it and riveted to the flanges of the arches and chords. Fig. 1453, which is a section on the abutment, fully explains the details. So far as the upper chords in the side spans are plated, the joints are of 7-in. beam section in place of channels, their lower flanges riveted to the plates, Figs 1454, 1455.

1453.

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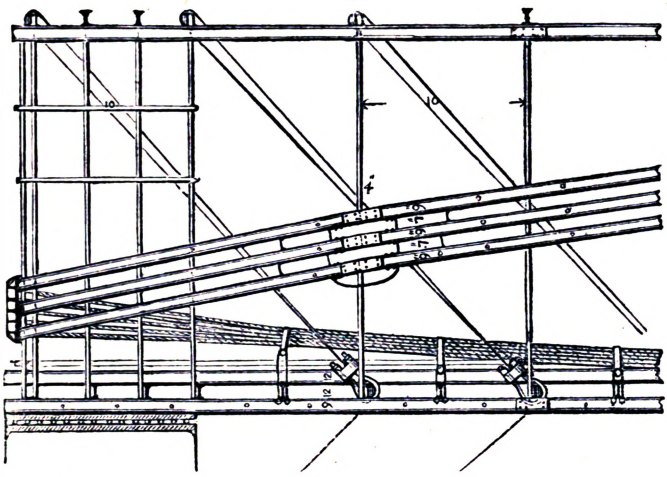

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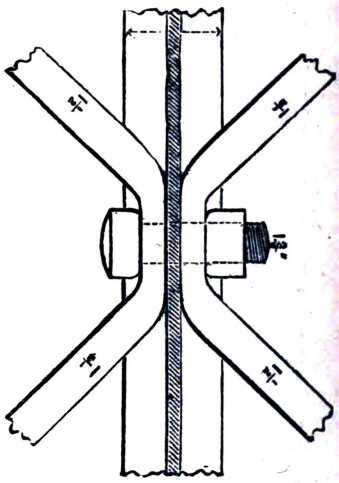


*Diagonals in Panels.*—The object of the panel-rods is to impart stiffness, and to spread any concentrated pressure over a large extent of truss. In the centre of the main span, the pressure upon any point is spread by these rods over 4 panels, or 80 ft. of length of truss. For every row of posts there is a plane of diagonals; consequently there are 4 lines, each rod $1\frac{1}{2}$ in. diameter, with screw-ends proportionally enlarged.

Fig. 1454 explains how two diagonals are joined in one, and how they are bolted to the stem of the post, between the upper chords.

It will be noticed that these rods all radiate toward central screw-rings, for the purpose of screwing them up to a proper tension, and thus to impart stiffness to the framing.

Any load upon any one point will make an impression upon 2 to 3 floor-beams, and 16 rods, of $1\frac{1}{2}$ in. diameter each, will be brought into service, and distribute the weight over a large extent of truss.

*Storm-cables.*—The arrangement of the storm-cables is fully explained by an inspection of Figs. 1428, 1429. Two wire-ropes of an ultimate strength of 100 tons each are suspended below the floor in such a manner as to form parabolic curves. By this plan no longitudinal strains are thrown upon the superstructure. All the strains are directed upon the floor-beams, and are regulated by screw-bolts to give the cables a proper tension. The horizontal deflection of these cables in the centre span is 41 ft., or about $\frac{1}{13}$ of the span, and therefore the coefficient of tension is 1·70. If we assume now that the force of a high wind should be so great as to produce a uniform horizontal pressure against the structure equal to 20 tons, then the strain on the cable would be $1{\cdot}70 \times 20 = 34$ tons, or about $\frac{1}{3}$ of its breaking strength. This tension might be

increased even to 50 tons without at all endangering the safety of the cables. But little surface is exposed to the wind vertically as well as horizontally.

It is well known that on a structure suspended at a high elevation, the wind exerts more of an uplifting power than of a horizontal action. The uplifting force is amply met by the weight of the structure itself. Estimating the vertical area exposed to horizontal action at 3000 sq. ft. and a pressure of 30 lbs. a sq. ft. applied all over, the aggregate pressure would be 90,000 lbs., and would be met by the strengh of the cables. In this calculation no allowance is made for the inherent stiffness of the horizontal framing at the upper and lower chords and the top of the arches.

As has been remarked before, an objectionable feature in the plan before us is the great height of the arches in the centre of the main span, and its tendency to lateral oscillations under the action of fast-moving trains or from the effects of heavy gusts of wind. Where, therefore, a necessity exists to preserve the whole space below the lower chords clear of all obstruction, either a double bridge must be erected at once, the two connected together, or a more effective horizontal bracing must be put up in localities which are exposed to very high winds or hurricanes. This horizontal security can be increased by heavier diagonal ties between the upper chords and arches, by doubling the storm-cables and by adding diagonal bracing. Any amount of security may thus be obtained. It will be noticed that the contractions and expansions of the storm-cables from changes of temperature are not at variance with those of the trusses, because they form one connected whole, and will always move together.

*Method of Raising the Superstructure.*—A most important question is the practicability, safety, and cost of erecting the superstructure of such large spans as here proposed. Short spans may be raised on temporary scaffolding, one span at a time, with facility and little risk. But the task of putting in place spans of great dimensions in a river which is subject to sudden rises, full of floating *debris*, and with an unstable bed, is formidable, and may in certain stages and at certain seasons become impracticable.

The history of the erection of the 500 ft. span of the Kuilenburg Bridge in Holland has furnished a practical demonstration of the difficulties involved in such an enterprise. Before the entire completion of the large span of that work, a heavy gale sprung up and demolished all the scaffolding, but left the trusses unaffected, their bearing parts having been previously all safely connected. Had this high wind occurred a few days sooner, the whole superstructure would have been thrown down a total wreck.

It may be of interest to notice here the method pursued by the contractor of the Coblenz Bridge (the same who put up the Kuilenburg Bridge) in raising the three arches of that work. The two halves of the arched ribs were completed on shore, then launched and floated on boats to their destination, whence they were raised to their permanent position and connected. The raising was done by a hydraulic press supported on a temporary scaffolding put up in the centre of the span. Arches of a little over 300 ft. may be managed in that way quite successfully and economically. But when the span is doubled, the drawbacks attending this process are also doubled, and it will be wise to consider other methods.

In comparing different plans of raising, the questions of relative economy and of speed of execution are of much less importance than is the question of *safety*. That method should be adopted which ensures absolute safety under all circumstances. Fortunately, the plans of superstructure here proposed, while exhibiting economy and strength, also admit of the safest mode of erection. The Parabolic Truss, as here devised and modified, is a combination of the suspension-cable and of the arch. If, therefore, we suspend the cable first, we may afterward suspend the arch to it, independent of scaffolding, flood, or ice. The whole work may be put up in this manner, without the use of any scaffolding whatever. Should the season and stage of water, however, be favourable to scaffolding, then a few light bends should be used, supported on piles and connected with the suspended platform by hemp-rope lashings, in such a manner that in the emergency of a sudden rise, the lashings may be cut in a few minutes, and the bends allowed to float off without doing any further harm. A few such light scaffold-frames put up, say every 50 or 100 ft., will much assist in preserving the proper level of the suspended platform, and therefore facilitate the joining of the various members of the structure. Those, particularly, who are without experience in suspended structures will find the assistance of bends very useful. But they are not a necessity, only a convenient auxiliary.

After the masonry of the first central pier has been completed, the erection of the wrought-iron shafts composing the tower will be commenced, and the saddles placed on top and secured. On the second centre pier where the superstructure is not to be fixed permanently, but allowed to contract and expand freely, the roller-plates and rollers have to be laid down first, before the erection of the towers can be proceeded with. The same must be done on the abutments. First lay down the roller-plates, then put up the posts, chords, and transverse beams, so far as the masonry furnishes support. Also put up the anchor-plates, and secure these to the posts. It is also necessary to secure the stability of the ends of the trusses on the abutment still further by temporary wooden and iron braces. Great security will be obtained from the lateral wire-rope braces, when put up and screwed tight.

A temporary anchorage will now have to be prepared for the purpose of meeting the strains caused by the cables. The wire-ropes provided for the storm-cables may be used for this purpose.

By making an excavation about 10 ft. deep and 25 ft. long by 25 ft. wide, and driving a few piles in front, using some of the 12-in. iron beams, railroad bars, timber, and stone, a temporary anchorage may be made, which will safely resist a strain of 500 tons.

In order to have the means of regulating the tension of the temporary anchor-cables, and to provide, to a certain extent, for contraction and expansion while engaged in raising, it will be advisable to deflect the anchor-cables a few feet, and anchor them in the centre between the anchorage and abutment to another temporary anchorage, or means of long screw-bolts and stirrups, or by block and tackle. This will afford the means of allowing the anchor-plates to

move forward towards the river just enough to close the arches and chords. Allowance must also be made for stretching the cables.

We have now proceeded far enough to take across the river two of the smaller cables or ropes which are to form parts of the large cables. An easy mode of accomplishing this will be to remove the reel which contains one coil of wire-rope upon the deck of a flat boat or barge, and to mount it upon a strong, well secured frame, on a spindle which rests on bearings, and is allowed to revolve Now provide one or two brakes to check and regulate the speed of the revolving reel, and employ a tug to tow the barge across the river, either above or below the line of piers.

The end of the rope should of course be first secured to one of the anchor-plates before starting. On crossing the river, the rope is simply dropped upon its bed. The other end being landed, is now temporarily secured to its anchor-plate, and preparations are made to hook up the rope at the centre piers, and to raise it to the top of the towers. Here it is rested on temporary timber-blocks, which serve as saddles, and are secured alongside of the cast-iron saddles.

After two wire-ropes have been taken across and suspended, their deflection must be adjusted, and they are then further secured to the middle towers by screw-clamps and bolts, to prevent their slipping. The object of these temporary suspension-cables being to facilitate the construction of the main cables, it is advisable to deflect them about 2 to 3 ft. *below* the main cables, so that they will run nearly parallel to them. This being done, light timber-beams or scantling, say 24 ft. long, may be thrown across the two opposite ropes, and lashed to them *from below* by hemp lines at distances of about 4 to 5 ft. apart. This process should commence at the two middle towers, and should be carried on both ways, so that the spans will be equally weighted, and their equilibrium maintained. Planks are pushed forward over the beams and secured by lashings, so that two foot-walks are formed, each about 4 ft. wide, in line of the main cables and underneath. Where these walks are very steep, the planks may be cleated, to secure a better foothold.

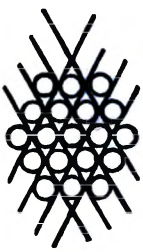
Two footways have now been put up, extending across the river from one abutment to the other. To facilitate the crossing of men not used to high elevations, two small wire-ropes ½ to ¾ in. diameter may be suspended just above the position of the main cables, and connected laterally every 50 ft. by smaller cords. The men will take hold of these ropes while crossing, and use them as hand-rails.

This being accomplished, we are now enabled to go from pier to pier and to perform work independent of the river. As the stays are placed in the bottom of the saddle, they must be raised first and put in place, allowing their ends to hang down the piers. This being done, the first permanent cable-rope may now be fastened to its anchor-plate at one end, then taken across the river and run off the reel in the same manner as before. These ropes are to be dropped upon the bed of the river, either above or below the piers, always on the side of their respective towers. Whenever a rope has thus been run off, it must be raised and placed upon the saddles before another one is launched on the bed of the river. It is also necessary that each rope should be properly placed and its deflection adjusted correctly before the next one is taken up.

The section of a saddle on Fig. 1437 exhibits plainly the different layers of rope. First, there are four laid down in the bottom, forming the first row; then one is added at each end in the second row. These six ropes are the stays. Next come the three ropes which compose the first or lowest layer in the cable; this is followed by a second row of four ropes; next comes the centre layer of five ropes; next, a layer of four ropes, and then the top layer of three ropes; the whole number of 19, which are in a cable, forming the section of a regular hexagon.

It is all-important that the five different layers should preserve their stratification and their proper level throughout the whole length of cable. To facilitate this operation, strips of canvas or strong cotton sheeting, say 3 in. wide, may be wrapped around each layer, and afterward again removed. Whenever a rope is added, it should be secured at various points by ties of fine annealed wire. The best plan, however, is to introduce short strips of tin, Fig. 1456, which cross each other diagonally, the whole being kept together by temporary wire or hemp strings. After all the 19 ropes have thus been suspended, adjusted, and collected into one cable, strong temporary wire-bands, made of No. 10 annealed wire, must be put around every 10 or 15 ft.; which operation will be greatly facilitated by using iron screw-clamps made in two halves, and fitting the section of the cable.

1456.



Referring to Figs. 1436, 1437, we notice that the lattice-beams which connect the opposite saddles of each tower may be omitted for the present, and that the two ropes for the footwalks may be supported on the cross-beams next below the lattice, which will be about the right elevation for cable-making.

It was remarked that the two ropes suspended temporarily for foot-walks are to be laid into the main cables *eventually*. This method is recommended for the sake of economy. But if some more wire-rope is on hand, strong enough for that purpose, then it will be better not to make temporary use of the permanent cable-ropes. It is supposed, however, that there is no spare rope on hand, and in that case two of the cable-ropes are to be suspended for foot-walks, one on each side. Now, after the other 18 ropes have been raised and adjusted in each main cable, the cross-beams which support the foot-plank may be suspended to the main cables by simply throwing small manilla ropes over in such a manner that they can be easily removed. This being done with all the beams, the two wire-ropes which supported the foot-planks are now free and may be raised into the saddles, adjusted to their proper levels in the various spans, and both ends secured. After this is done, the manilla suspenders over the main cables are now lifted, one after another, and thrown over the last wire-rope, and again fastened to their respective beams. The cables are now ready for the permanent suspenders and straps. The latter are heated at one corner, so that they may be readily closed and screwed up tight. To prevent injury to the cable, a piece of sheet iron is laid around it: the strap is then closed and cooled off with water. A small hand-forge may be moved along on the suspended scaffolding for that purpose.

It will be a somewhat difficult task for those not experienced in the construction of wire-cable bridges, to get the cable straps and suspenders properly spaced.

Measurements from the towers being uncertain and the cables movable, no satisfactory adjustment can be effected in this way. But, either by calculation or actual suspension, or both, measure off the actual distances upon a small wire-cord, or upon a single wire. These distances in the suspended cable form the hypothenuses of right-angled triangles, the horizontal base of which is a *constant*, equal to the horizontal distance of the suspenders. The vertical is variable, and is equal to the difference of the lengths of the two adjoining suspenders. These triangles may all be laid off on one board, and the length of the hypothenuses transferred upon the wire-cord and marked by small wrappings made of fine wire, so that they cannot be shifted. This wire line is then suspended alongside of the centre of the cable, and whitelead marks are put upon the latter, which will correspond to the centre of the suspended ropes.

These measurements and marks being correctly made, there will be no further difficulty in spacing the suspenders correctly; their length will come out nearly correct, and the beams suspended to them will be found equally spaced.

The main cables being completed, they should be further secured in their saddles by bolting down those cushions which are to prevent their slipping. A temporary platform must next be suspended below the level of the lower chords, strong enough to support 1 ton a foot lineal. The suspenders being 10 ft. apart, timber-beams 24 ft. long, about 8 × 14, may be suspended to them by means of temporary stirrups, so made that the level may be adjusted. A plank-walk about 5 ft. wide should then be laid down under each cable. The next step is to lay down upon these plank-walks the channel-bars which are to form the lower chords. Care must be had to distribute those bars evenly and uniformly on each side of a pier, and in all the spans at the same time, so that the equilibrium of the cables is not much disturbed. This distribution being properly made, the bars may be connected by bolts temporarily, and partly spliced, but so that the posts can afterward be set up between.

In order to add to the weight of the platform, and increase its stability, the truss-posts should now be distributed uniformly, and laid down alongside of the chords, all over the work. It may also be the proper time to make use of the main-stays, and to attach their ends temporarily to the lower chords, and to the platform. When up, they will not only add to the supporting power, but also to the steadiness of the platform. The whole process of erection will be much facilitated by a narrow track, laid down in the centre of the platform between the two walks, for the support of a few small trucks, on which the bars may be transported from both abutments. With a favourable stage of water in the river, the delivery of materials may also be forwarded by boats moored at the piers and hoisting the bars up, then distributing on trucks.

The work has now so far progressed that we may proceed to put up the posts. There are several methods by which this may be accomplished. One plan is to proceed from the centre piers each way toward the main span and the side spans uniformly at the same time. As soon as one or two sets of posts are up, connect them by the upper chords, and also secure the latter by transverse beams and temporary wooden braces Next put in place the panel-rods, which will increase the stiffness of the framing considerably.

While this process of building out from the piers is going on, the level of the platform must be maintained at the same time, by distributing the bars for the posts and chords all along. The weights being uniformly distributed, the level will be preserved, and the steadiness of the platform will also be increased. A few small wire-ropes may likewise be applied below the platform, fastened to the masonry of the piers, to serve as storm-cables, in case of a heavy blow. Before commencing with the arches, the posts and upper chords may be put up through the balance of the spans, the panel-rods put in, the cross-connections made, and the trusses nearly completed.

Changes of temperature, causing expansion and contraction, may be accommodated by placing the lower chords on wooden rollers about 6 in. diameter.

Slight changes will not be noticed; but should great changes take place, and produce considerable contractions and expansions, it will be good policy to provide slip-joints in the chords as well as the arches at various points, and use a few temporary splicing-plates to that effect, or timbers bolted on sideways. No rigid connection should be made at any place: no riveting before the whole structure is up.

It was remarked that the whole superstructure may be put up and completed without the assistance of scaffolding. This can be done, if absolutely necessary. We therefore propose to scaffold one of the side spans or both, leaving the central span open for navigation. This being done, we may put up the arches in the two side spans, and also put up one transverse iron beam every 20 ft., to give a good, permanent lateral connection to the lower floor. By the completion of the arches of the side spans, the resistance of the anchor-plates will have been much increased.

One half of the bents under the side spans may now be removed with safety, and put under the spring of the arches in the central opening; and as much material may also be distributed over the platform of the central span as will be necessary to balance the side spans. By this distribution we shall maintain the equilibrium of the cables. The thrust of the arches in the side spans will be fully met by the lower chords, which should be completed; so that it may be safe to remove all the bents from under the side spans and put them up in the centre opening. This being done, the closing of the arches in the centre is now to be accomplished, and the trusses may be sufficiently completed to render a further support by scaffolding unnecessary.

If, during the process of erection, a sudden flood should occur, or floating masses of ice endanger the safety of the scaffoldings, the latter should be watched day and night, and cut loose if necessary. This may cause some delay, but no further damage.

If the spring of the arches descends below the lower chords, the raising of the superstructure will be easier; and this plan should always be adopted if possible.

*Statement of the Strains in the different members of a Trussed Girder Bridge of 300 ft. span in the clear.*—This iron truss alone weighs 0·85 ton a ft., and is proportioned to sustain its own weight

PANELS.

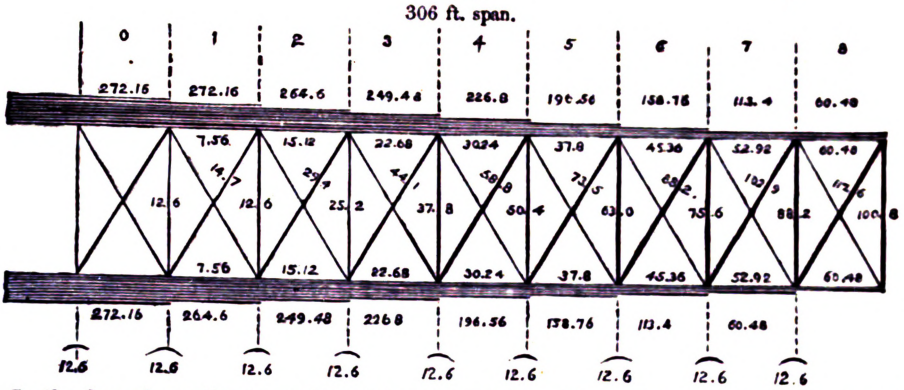
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total Weight of 9 Panels. | Total Weight of 8 Panels. | Aggregate. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight and load, a panel, for one truss .. .. | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | Tons. 12·6 | | | |
| 2 Tie-rods .. | Tension .. .. .. .. | 0 | 14·7 | 29·4 | 44·1 | 58·8 | 73·5 | 88·2 | 102·9 | 117·6 | | | |
| | Sq. section by calculation | 0 | 2·94 | 5·88 | 8·82 | 11·76 | 14·70 | 17·64 | 20·58 | 23·52 | | | |
| | Weight a ft. .. .. .. | 0 | 9·88 | 19·76 | 29·64 | 39·51 | 49·39 | 59·27 | 69·15 | 79·03 | | | |
| | Length in ft. .. .. .. | 0 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | | | |
| | Weight in lbs. .. .. | 0 | 345·8 | 691·6 | 1037·4 | 1382·8 | 1728·6 | 2074·5 | 2420·3 | 2766·1 | 12,447·1 | 12,447·1 | 24·894·2 |
| 1 Counter-rod | Sq. section allowed .. | 1·75 / 1·75 sq. in. | 1·75 | 1·75 | 1·75 | 1·75 | 1·75 | 1·75 | 1·75 | 1·75 | | | |
| | Weight a ft. .. .. .. | 5·9 / 5·9 | 5·9 | 5·9 | 5·9 | 5·9 | 5·9 | 5·9 | 5·9 | 5·9 | | | |
| | Length in ft. .. .. .. | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | | | |
| | Weight in lbs. .. .. | 206·5 / 206·5 | 206·5 | 206·5 | 206·5 | 206·5 | 206·5 | 206·5 | 206·5 | 206·5 | 2,065 | 1,652 | 3,717 |
| 2 Posts .. | Compression .. .. .. | 12·6 | 12·6 | 25·2 | 37·8 | 50·4 | 63 | 75·6 | 88·2 | 100·8 | | | |
| | Sq. section by calculation | 3·15 | 3·15 | 6·3 | 9·45 | 12·6 | 15·75 | 18·9 | 22·05 | 25·2 | | | |
| | Sq. section allowed .. | 12 | 12 | 12 | 12 | 12·6 | 15·75 | 18·9 | 22·05 | 25·2 | | | |
| | Weight a ft. .. .. .. | 40 | 40 | 40 | 40 | 42·3 | 52·9 | 63·5 | 74·1 | 84·7 | | | |
| | Length in ft. .. .. .. | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | | | |
| | Weight in lbs. .. .. | 1200 | 1200 | 1200 | 1200 | 1269 | 1587 | 1905 | 2223 | 2541 | 1-, | 14,325 | 28,650 |
| Lower chords | Tension .. .. .. .. | 272·16 | 264·6 | 249·48 | 226·8 | 196·56 | 158·76 | 113·4 | 60·48 | 3·67 | | | |
| | Sq. section by calculation | 54·432 | 52·92 | 49·896 | 45·36 | 39·312 | 31·752 | 22·68 | 12·096 | 0·734 | | | |
| | Sq. section allowed .. | 54·432 | 52·92 | 49·896 | 45·36 | 39·312 | 31·752 | 22·68 | 18 | 18 | | | |
| | Weight a ft. .. .. .. | 182·9 | 177·8 | 167·6 | 152·4 | 132·1 | 106·7 | 76·2 | 60·5 | 60·5 | | | |
| | Length in ft. .. .. .. | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | | |
| | Weight in lbs. .. .. | 3292·2 | 3200·4 | 3016·8 | 2743·2 | 2377·8 | 1920·6 | 1371·6 | 1089 | 1089 | 20,100·6 | 16,808·4 | 36,909 |
| Upper chords | Compression .. .. .. | 272·16 | 272·16 | 264·6 | 249·48 | 226·8 | 196·56 | 158·76 | 113·4 | 60·48 | | | |
| | Sq. section by calculation | 68·04 | 68·04 | 66·15 | 62·37 | 56·7 | 49·14 | 39·69 | 28·35 | 15·12 | | | |
| | Weight a ft. .. .. .. | 228·61 | 228·61 | 222·3 | 209·6 | 190·5 | 165·1 | 133·4 | 95·3 | 50·8 | | | |
| | Length in ft. .. .. .. | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | | |
| | Weight in lbs. .. .. | 4114·9 | 4114·9 | 4001·4 | 3772·8 | 3429·0 | 2971·8 | 2401·2 | 1715·4 | 914·4 | 27,435·8 | 23,320·9 | 50,756·7 |

| | |
|---|---|
| Total aggregate weight .. .. .. | 144,927 |
| Add one-half the additional weight of floor-beams, rails, cross-bracing, and so on .. .. .. .. .. .. .. | 93,836 |
| Add one-half the extra items—rivets, bolt-heads, nuts, splicing-plates, and so on .. .. .. .. .. .. .. | 21,337 |
| Total weight of one-half the bridge, or one line of truss .. .. .. .. | 260,100 lbs. |
| Weight of whole bridge = .. .. .. .. .. .. .. .. .. .. | 260·1 tons. |

and a moving load of 1100 lbs. The wire cables support a moving load of only 1900 lbs. a ft., Fig. 1457. Tension allowed in iron is 5 tons the sq. in. The compression allowed is 4 tons the sq. in. Panel = 18'.

1457.

306 ft. span.

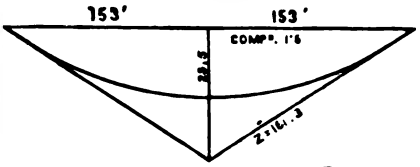



In the foregoing estimate, we have taken the weight on the bridge at 1·4 ton a ft. run. The weight of the structure itself is $\frac{260 \cdot 1}{306} = 0 \cdot 85$ ton a ft. run. The bridge will therefore support, in addition, a moving load of 1·4 — 0·85 = 0·55 ton, or 1100 lbs. a ft. run.

| | lbs. a ft. |
|---|---|
| Moving load .. .. .. .. .. .. .. | 1900 |
| Top plate .. .. .. .. .. .. .. | 490 |
| Cable .. .. .. .. .. .. .. .. | 123 |
| Suspender .. .. .. .. .. .. .. | 28 |
| Total weight supported by cables .. | 2541 |

1458.

Steel Cables.




| | Tons. |
|---|---|
| Total weight for whole bridge = 2541 lbs. × 306' = 777,546 lbs. = .. .. .. | 388·77 |
| Tension in cable, 1·58 × 388·77 tons = .. .. .. .. .. .. .. .. .. | 614·25 |
| Compression, Fig. 1458, in upper chord due to the cable = 1·5 × 388·77 tons = | 583·16 |

The cable being much smaller in this example than in the previous one, each will consist of only seven ropes: and taking the maximum tension allowed as before, at 5 tons a pound a ft., we have the strength of one rope = $\frac{614 \cdot 25}{14} = 43 \cdot 88$ tons; and the weight a ft. of such a rope is $\frac{43 \cdot 88}{5} = 8 \cdot 78$ lbs. The diameter of this rope is $2\frac{5}{16}$ in., and the diameter of one cable 7 in.

*Compression.*—The section required in the top plate is $\frac{583 \cdot 16}{4} = 145 \cdot 79$ sq. in. Weight a ft. = 145·79 × 3·36 = 490 lbs.

Some of this weight will be thrown upon the channel-bars, as in the previous case.

The heaviest section of channel-bar is 56 sq. in., equal to 142 lbs. a yard.

The section required for one top plate is $\frac{145 \cdot 79}{2} = 72 \cdot 895$. Hence we have left for the top plate 72·895 — 56 = 16·895 sq. in.

In order to keep the channel-bars of a uniform section throughout, we will add to this top plate the varying sections of upper chord, required by the structure alone, in the calculation above. The following Table shows how this is done; the sixth line gives the number of sq. in. of section required in the top plate in each panel.

TABLE OF SECTIONAL AREA OF TOP PLATE IN EACH PANEL.

| Number of Panels. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Total section of one top plate .. .. | 72·895 | 72·895 | 72·895 | 72·895 | 72·895 | 72·895 | 72·895 | 72·895 | 72·895 |
| Section required for upper chord of structure .. .. | 68·040 | 68·040 | 66·150 | 62·370 | 56·700 | 49·140 | 39·690 | 28·350 | 15·120 |
| Aggregate section .. | 140·935 | 140·935 | 139·045 | 135·265 | 129·595 | 122·035 | 112·585 | 101·245 | 88·015 |
| Deduct assumed section of channels .. | 56·000 | 56·000 | 56·000 | 56·000 | 56·000 | 56·000 | 56·000 | 56·000 | 56·000 |
| Leaves for section of top plate .. .. | 84·935 | 84·935 | 83·045 | 79·265 | 73·595 | 66·035 | 56·585 | 55·245 | 32·015 |
| Dimensions of top plate | in. in. 42 × 2·02 | in. in. 42 × 2·02 | in. in. 42 × 1·98 | in. in. 42 × 1·88 | in. in. 42 × 1·75 | in. in. 42 × 1·57 | in. in. 42 × 1·34 | in. in. 42 × 1·08 | in. in. 42 × 0·76 |

*Recapitulation of whole Weight.*

| | lbs. |
|---|---|
| Tie-rods, counter-rods, posts, upper and lower chords on one side .. .. | 144,927 |
| Additional weight on one side .. .. .. .. .. .. .. .. .. .. .. | 93,836 |
| Extra items .. .. .. .. .. .. .. .. .. .. .. .. .. .. | 21,337 |
| Weight of top plate on one side, 72·895 sq. in. × 3·36 lbs. = 245 lbs., and 245 × 306 = .. .. .. .. .. .. .. .. .. .. | 74,970 |
| Cable = 8·78 lbs. × 7 = 61·5 × 312 ft. = .. .. .. .. .. .. .. | 19,188 |
| Suspenders = 14 × 306 = .. .. .. .. .. .. .. .. .. .. .. | 4,284 |
| One-half weight of whole structure .. .. .. .. .. .. | 358,542 lbs. |
| Total weight of the entire structure .. .. .. .. .. .. | 358·542 tons. |

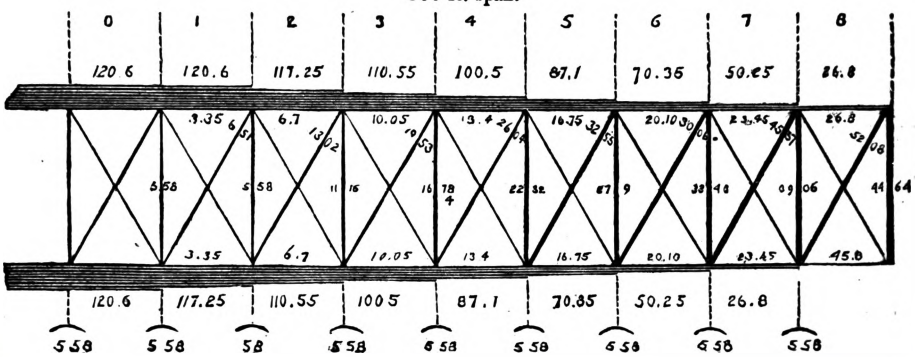
$$\text{Weight a foot} = \frac{358{,}542}{306} = 1{\cdot}171 \text{ ton.}$$

*Statement of the Strains in the different members of a Trussed Girder Bridge of* 300 *ft. span in the clear.*—The iron truss alone weighs 0·62 ton a foot, and is proportioned to sustain only its own weight, while the moving load of 3000 lbs. a foot is supported by wire cables, Fig. 1459.

The tension allowed in iron is 5 tons to a sq. in. The compression allowed is 4 tons to the sq. in. Length of one panel = 18 in.

1459.

306 ft. span.




In the foregoing estimate we took the weight of the bridge at 0·62 ton a foot run. This agrees with the result here obtained, since 0·62 × 306 = 189·72 tons.

Let us now put in a pair of steel cables to support, 1st, the moving load; 2nd, the weight of the top plate required to resist the compression due to the cable; and, 3rd, the weight of the cables and of the suspenders.

| | lbs. |
|---|---|
| Moving load .. .. .. .. .. .. .. .. | 3000 |
| Top plate .. .. .. .. .. .. .. .. | 771 |
| Cable .. .. .. .. .. .. .. .. | 193 |
| Suspenders .. .. .. .. .. .. .. .. | 36 |
| Total weight on cables a foot run .. | 4000 |

| | Tons. |
|---|---|
| Total weight for whole bridge, 4000 × 306 = .. .. .. .. .. .. | 612 |
| Tension in cable = 1·58 × 612 tons = .. .. .. .. .. .. .. | 967 |
| Compression in upper chord due to cable = 1·5 × 612 tons = .. .. .. | 918 |

The ultimate strength of good steel cables is 25 tons a lb. the foot, which is equivalent to 176,000 lbs. a sq. in. solid wire-section; the maximum tension allowed is 5 tons a lb. to the foot. We have two cables, one on each side, each containing nineteen wire-ropes. Hence the strength of one rope is $\frac{967}{38} = 25{\cdot}45$ tons; and the weight a foot of such a rope is $\frac{25{\cdot}45}{5} = 5{\cdot}09$ lbs. a foot. The diameter of this rope is 1·7 in., and the diameter of one cable of nineteen ropes is 8½ in.

*Compression.*—The section required in the top plate is $\frac{918}{4} = 229{\cdot}5$. Weight a foot = 229·5 × 3·36 = 771·0 lbs.

In place of putting all this section into a plate, it is better to divide it by increasing the section of the channel-bars in the upper chord somewhat; especially since the sections of channel-bars obtained in the calculation above were so small that they could not be executed in practice. Let us increase the sections of the four channels in one upper chord to 56 sq. in., which is equal to 142 lbs. a yard for each channel-bar, the heaviest section rolled. The section required for one top plate is $\frac{229{\cdot}5}{2} = 114{\cdot}75$ sq. in. Hence we have left for the top plate 114·75 − 56 = 58·75 sq. in.

In order to keep the channel-bars of a uniform section throughout, we will also add to this top plate the varying sections of upper chord, required by the structure alone, in the calculation

## PANELS.

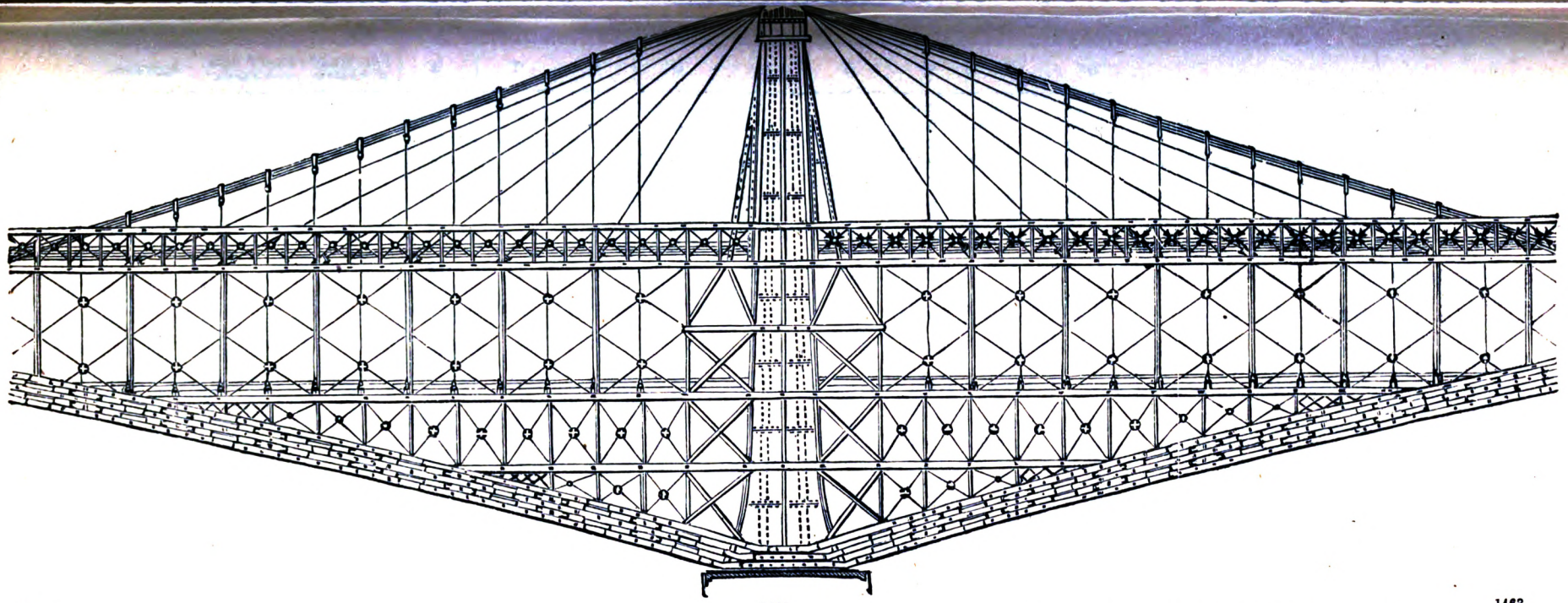
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total Weight of 9 Panels. | Total Weight of 8 Panels. | Aggregate. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | | | |
| | Weight a panel for one truss | 5·58 | 5·58 | 5·58 | 5·58 | 5·58 | 5·58 | 5·58 | 5·58 | 5·58 | | | |
| 2 Tie-rods .. | Tension .. .. .. .. | 0 | 6·51 | 13·02 | 19·53 | 26·04 | 32·55 | 39·06 | 45·57 | 52·08 | | | |
| | Sq. section by calculation | 0 | 1·302 | 2·604 | 3·906 | 5·208 | 6·510 | 7·812 | 9·114 | 10·416 | | | |
| | Sq. section allowed .. | 0 | 2 | 2·604 | 3·906 | 5·208 | 6·510 | 7·812 | 9·114 | 10·416 | | | |
| | Weight a ft. .. .. .. | 0 | 6·72 | 8·75 | 13·12 | 17·49 | 21·87 | 26·25 | 30·62 | 35·0 | | | |
| | Length in ft. .. .. .. | 0 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | | | |
| | Weight in lbs. .. .. .. | 0 | 235·2 | 306·3 | 459·2 | 612·2 | 765·5 | 918·8 | 1071·7 | 1225 | 5,593·9 | 5,593·9 | 11,187·8 |
| 1 Counter-rod | Sq. section allowed .. | 1½ 1½ sq. in. | 1½ | 1½ | 1½ | 1½ | 1½ | 1½ | 1½ | 1½ | | | |
| | Weight a ft. .. .. .. | 5·04 5·04 | 5·04 | 5·04 | 5·04 | 5·04 | 5·04 | 5·04 | 5·04 | 5·04 | | | |
| | Length in ft. .. .. .. | 35 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | | | |
| | Weight in lbs. .. .. .. | 176·4 176·4 | 176·4 | 176·4 | 176·4 | 176·4 | 176·4 | 176·4 | 176·4 | 176·4 | 1,764 | 1,411·2 | 3,175·2 |
| 2 Posts .. | Compression .. .. .. | 5·58 | 5·58 | 11·16 | 16·74 | 22·32 | 27·9 | 33·48 | 39·06 | 44·64 | | | |
| | Sq. section by calculation | 1·395 | 1·395 | 2·79 | 4·185 | 5·58 | 6·975 | 8·37 | 9·765 | 11·16 | | | |
| | Sq. section allowed .. | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | | |
| | Weight a ft. .. .. .. | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | | | |
| | Length in ft. .. .. .. | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | | | |
| | Weight in lbs. .. .. | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 | 10,800 | 10,800 | 21,600 |
| Lower chords | Tension .. .. .. .. | 120·6 | 117·25 | 110·55 | 100·5 | 87·10 | 70·35 | 50·25 | 26·8 | 3·35 | | | |
| | Sq. section by calculation | 24·12 | 23·450 | 22·11 | 20·1 | 17·42 | 14·07 | 10·05 | 5·36 | 0·670 | | | |
| | Sq. section allowed .. | 24·12 | 23·45 | 22·11 | 20·1 | 18 | 18 | 18 | 18 | 18 | | | |
| | Weight a ft. .. .. .. | 81·04 | 78·79 | 74·29 | 67·54 | 60·48 | 60·48 | 60·48 | 60·48 | 60·48 | | | |
| | Length in ft. .. .. .. | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | | |
| | Weight in lbs. .. .. .. | 1458·7 | 1418·2 | 1337·2 | 1215·7 | 1088·64 | 1088·64 | 1088·64 | 1088·64 | 1088·64 | 10,873 | 9,414·3 | 20,287·3 |
| Upper chords | Compression .. .. .. | 120·6 | 120·6 | 117·25 | 110·55 | 100·5 | 87·10 | 70·35 | 50·25 | 26·8 | | | |
| | Sq. section by calculation | 30·15 | 30·15 | 29·31 | 27·64 | 25·125 | 21·775 | 17·59 | 12·56 | 6·7 | | | |
| | Weight a ft. .. .. .. | 101·3 | 101·3 | 98·5 | 92·9 | 84·4 | 73·2 | 59·1 | 42·2 | 22·5 | | | |
| | Length in ft. .. .. .. | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | | |
| | Weight in lbs. .. .. .. | 1823·4 | 1823·4 | 1773 | 1672·2 | 1519·2 | 1317·6 | 1063·8 | 759·6 | 405·0 | 12,157·2 | 10,333·8 | 22,491·0 |

### ADDITIONAL WEIGHT.

| | lbs. |
|---|---|
| Weight of 51 floor-beams, iron, 12 in. deep × 20 ft. 6 in. long, at 820 lbs. each .. .. | 41,820 |
| .. 2 longitudinal girders, 9 in. deep under track, 2 × 306 × 25 lbs. .. .. | 15,300 |
| .. 36 pairs of 9 in. overhead cross-channels, 20 ft. 6 in. long, at 328 lbs. each .. | 23,616 |
| .. corner braces, 86 × 132 .. .. .. .. .. .. .. .. .. .. .. .. | 4,752 |
| .. rods and rings of vertical cross-bracing .. .. .. .. .. .. .. | 6,244 |
| .. lattice and connecting-bars of 18 sets of truss posts, at 1056 lbs. .. .. .. | 19,008 |

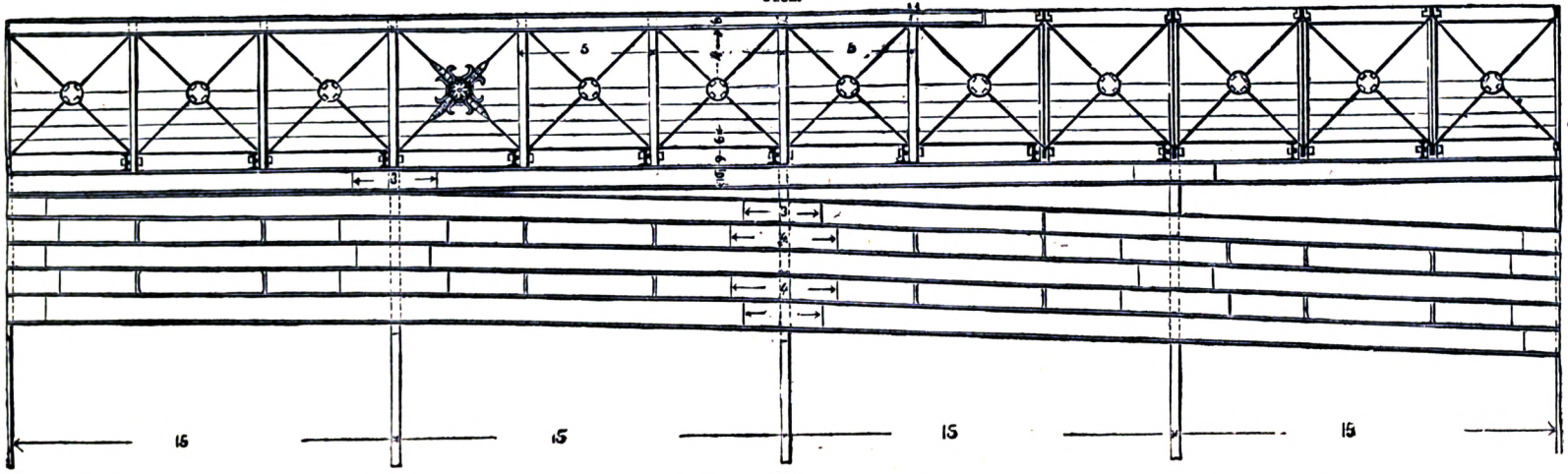
| | lbs. |
|---|---|
| Weight of 2 sets of overhead horizontal tie-rods and rings, 1½ in. diam., 568 lbs. × 18 .. | 10,224 |
| .. iron rails, 75 lbs. a yd. .. .. .. .. .. .. .. .. .. .. .. | 15,300 |
| .. wooden stringers and bridging .. .. .. .. .. .. .. .. .. .. | 51,408 |
| Total .. .. .. .. .. .. | 187,672 |

| | |
|---|---|
| Total .. .. .. | 78,741·3 |
| One-half this amount for a single truss .. .. .. .. .. .. .. .. .. .. .. .. | 93,836 |
| Weight of extra items, comprising all the splicing-plates of the channel-bars, the rail splices, spikes, clamps, stirrups, rivet-heads, bolt-heads and nuts, short bolts, washers, and so on .. | 17,142·7 |
| Total aggregate weight of one single line of truss .. .. .. .. .. .. .. .. .. | 189·720 lbs. |
| Total aggregate weight of the whole bridge .. .. .. .. .. .. .. .. .. .. | 189·72 tons. |



1461

1462.

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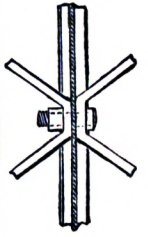


above. The following Table shows how this is done: the sixth line gives the number of sq. in. of section required in the top plate in each panel.

TABLE OF SECTIONAL AREA OF TOP PLATE IN EACH PANEL.

| Number of Panel. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Total section of one top plate .. .. | 114·75 | 114·75 | 114·75 | 114·75 | 114·75 | 114·75 | 114·75 | 114·75 | 114·75 |
| Section required for upper chord of structure .. .. | 30·15 | 30·15 | 29·31 | 27·64 | 25·12 | 21·775 | 17·59 | 12·56 | 6·7 |
| Aggregate section .. | 144·90 | 144·90 | 144·06 | 142·39 | 139·87 | 136·525 | 132·34 | 127·31 | 121·45 |
| Deduct assumed section of channels .. | 56·00 | 56·00 | 56·00 | 56·00 | 56·00 | 56·00 | 56·00 | 56·00 | 56·00 |
| Leaves for section of top plate .. .. | 88·90 | 88·90 | 88·06 | 86·39 | 83·87 | 80·525 | 76·34 | 71·31 | 65·45 |
| Dimensions of top plate | in. in. 42 × 2·11 | in. in. 42 × 2·11 | in. in. 42 × 2·09 | in. in. 42 × 2·05 | in. in. 42 × 1·99 | in. in. 42 × 1·92 | in. in. 42 × 1·81 | in. in. 42 × 1·70 | in. in. 42 × 1·55 |

*Recapitulation of whole Weight.*

| | lbs. |
|---|---|
| Tie-rods, counter-rods, posts, upper and lower chords on one side .. .. | 78,741·3 |
| Additional weight on one side .. .. .. .. .. .. .. .. .. .. .. .. | 93,836·0 |
| Extra items .. .. .. .. .. .. .. .. .. .. .. .. .. | 17,142·7 |
| Weight of top plate on one side, 114·75 × 3·36 = 385·5 per foot, or 385 × 5 × 3·06 = .. .. .. .. .. .. .. .. .. .. | 117,963·0 |
| One cable, 312 ft. × 19 × 5·09 lbs. .. .. .. .. .. .. .. .. | 30,173·0 |
| Suspenders, &c., 36 × 306, or, for one side, 18 × 306 .. .. .. .. .. | 5,508·0 |
| One-half weight of whole structure .. .. .. .. .. .. | 343,364 lbs. |
| Total weight of the entire structure .. .. .. .. .. .. | 343·36 tons. |

$$\text{Weight per foot} = \frac{343 \cdot 36}{306} = 1 \cdot 122 \text{ ton.}$$

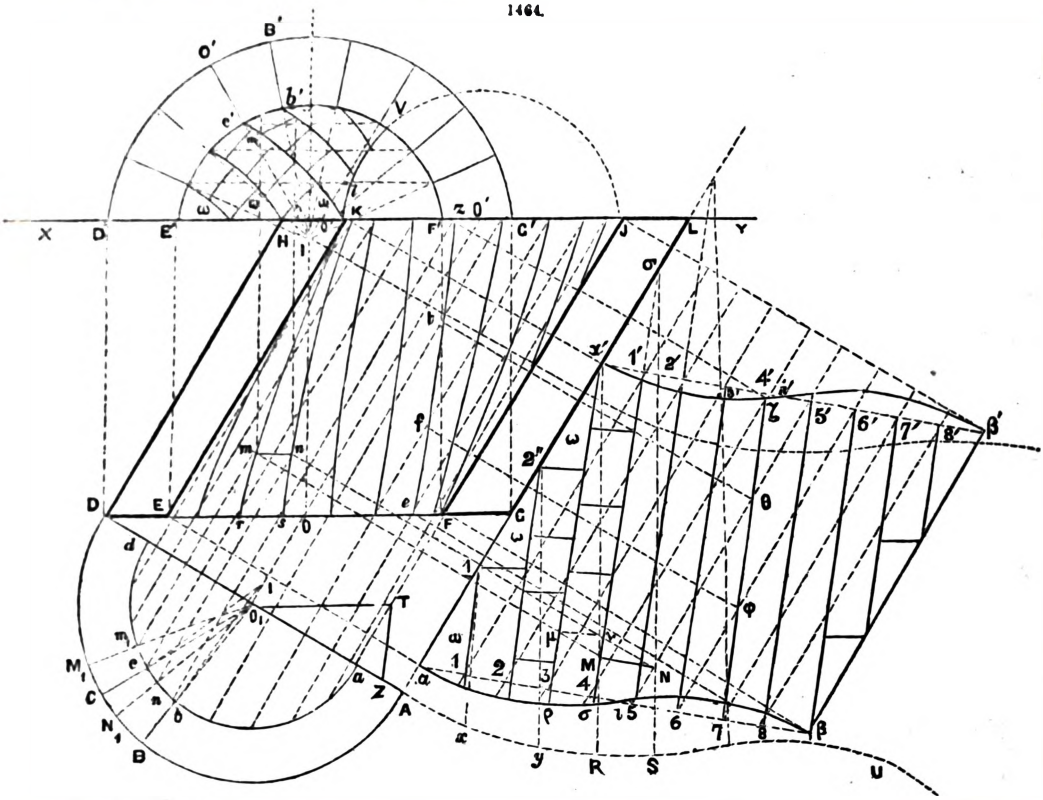
For further particulars respecting this system, the reader is referred to Roebling's large work, published by D. Van Nostrand, N.Y.

*Oblique Bridges* are bridges in which the axis of the arch meets the supports in an oblique direction. Railways have much necessity for this kind of bridges, because the survey frequently makes it necessary to carry the track over a road or a canal, which it intersects at an angle more or less acute. From obvious economical considerations, only the leading arches and courses of the springers are constructed of hewn stone; the body of the arch is formed of materials of a weaker description, often of bricks. These considerations have led engineers to the conception of a plan appropriate to this kind of construction. Three principal systems are at present in use in the construction of *oblique bridges:* the helicoidal arrangement, which was originated in England; the orthogonal arrangement, invented in France; and that of upright arches *en retraite*, a very ancient system lately brought into use. In each of the two first systems, the arch is semicircular, and it is the mode of its subdivision into voussoirs which distinguishes it from ordinary semicircular arches.

*The Helicoidal Arrangement.*—This is so named from the fact that the edges of the inward arch are spirals, and the bed-joints, as well as the upright joints, are helicoidal surfaces of square-threaded screws. This arrangement is determined in the following manner:—Let E K and F J, Fig. 1464, be the spring lines of the intrados, D H and G L those of the extrados; H L and D G the horizontal draughts of the principal planes: let E′ V F′ and K V J be the vertical projections of the intersections of these principal planes with the intrados; let D′ C′ B′ G′ be the projection of the intersection of the extrados on the plane D G; finally, let *a b c d* and A B C D be the upright sections of the intrados and extrados, developed upon the plane of the spring, which is here the horizontal plane. We will suppose these upright sections to be circles, and commence by constructing at $\alpha\beta\beta'\alpha'$ the development of the intrados: we draw the chords $\alpha\beta$ and $\alpha'\beta'$, dividing them into the same number of equal parts, at the points 1, 2, 3, and so on; 1′, 2′, 3′, and so on. We join any one point of division of $\alpha'\beta'$ with a point of division of $\alpha\beta$, so chosen that the line of junction differs as little as possible from a perpendicular common to the two chords $\alpha\beta$ and $\alpha'\beta'$. We see here, for example, that to fulfil these conditions it is necessary to join the point 4′ to the point 7; in the same way the point 3′ to the point 6, the point 2′ to the point 5, and so on; the point 5′ to the point 8, and so on with the rest. We shall thus obtain a series of parallel and equidistant right lines. The number of the divisions of $\alpha\beta$ or $\alpha'\beta'$ should be regulated in such a manner that the distance of two consecutive parallels should be equal to the thickness of the materials which are intended to be used for the body of the arch, or should only slightly exceed that thickness. If we imagine the figure $\alpha\beta\beta'\alpha'$ to be applied upon the cylinder of the intrados, the parallels in question will become spiral parallels. These are the spirals which are taken as a guide for the edges of the inward arch. We obtain the projections of these spirals in the following manner:—If from the points of division of $\alpha\beta$ and $\alpha'\beta'$, which occupy the same level, we draw right lines, they will be parallel to the axis O O′ of the arch, and will be nothing more or less than the generatrices of the intrados. To obtain the projections of these generating lines, we must divide the half-circumference *a b c d* into as many equal parts as $\alpha\beta$; and from the points of division

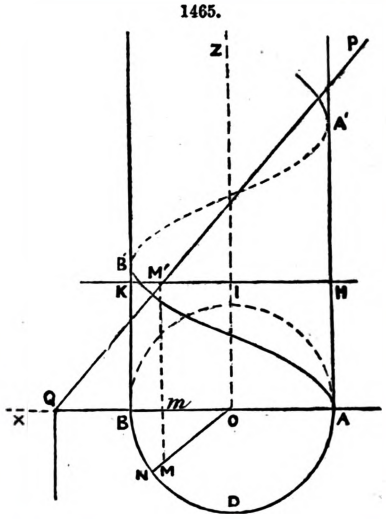
draw parallels to O O′; these are the horizontal projections of the generating lines. From the points where these projections meet the right line E F, we draw perpendiculars to the base line X Y; the points where these perpendiculars meet the semi-ellipse E′ V F′ will belong to the vertical projections of the corresponding generatrices; and, by drawing from these last points lines

1464.




parallel to X Y, we shall have the vertical projections themselves. This being understood, if we wish to obtain, for example, the horizontal projection of the generating line 4′ 7, we mark the points $\epsilon$, $\phi$, $\theta$, $\zeta$, where it meets successively the leading curve $\alpha i \beta$, the generatrix 6·6′, the generatrix 5·5′, and the leading curve $\alpha' i' \beta'$; from these points we draw lines perpendicular to O O′, ending respectively on the right line E F, the horizontal projection of the generatrix 6·6′, on that of the generatrix 5·5′, finally on the right line K J; we shall thus obtain four points, *e*, *f*, *t*, *z*, of the required projection, and it will be easy to trace this projection. In the same manner, the horizontal projection of the other spirals will be obtained: they are marked in dark lines in the quadrilateral E F J K. To obtain the vertical projection of a spiral, it is necessary to mark the points where its horizontal projection meets the horizontal projections of the different generatrices of the cylinder, and from these points to draw lines perpendicular to the base line, until they meet the vertical projections of the same generatrices: we thus obtain the curves *c′ k*, *b′ l*, and so on.

1465.




*Spiral surfaces with a square-threaded twist* are taken for the bed-joints; that is, each of these joints is governed by a right line subject to remain parallel to the plane of the upright section of the cylinder, and to rest constantly upon the axis O O′ of this cylinder, and upon the spiral which forms the edge of the inner arch corresponding to the joint under consideration. Before going further, it is necessary to determine the intersection of these spiral joints with the leading planes. The intersection of a spiral surface with a plane may be constructed by the ordinary methods of descriptive geometry. Let us suppose that the vertical line O I, Fig. 1465, is the axis of the surface; and that the directing spiral has for its horizontal projection the circumference O A, and for its vertical projection the sinusoid A B′ A′ . . . . . ; and let P Q be the vertical tracing of the intersecting plane, supposed to be perpendicular to the vertical plane of projection. Draw any auxiliary horizontal plane K H; this auxiliary plane will intersect the helicoidal surface according to a horizontal line which is projected vertically upon K H, and horizontally according to a radius O N, which will be determined by the condition that the arc A D N shall be to the entire circumference in the

ratio of A H to the space A A'. The same auxiliary plane will intersect the plane P Q, according to a line perpendicular to the vertical plane, which is projected vertically according to the point M', and horizontally, according to a line $m$ M, perpendicular to the base line. The point M, M', belonging at the same time to the generatrix $I H_1 O N_2$, and to the intersection of the auxiliary and the intersecting planes, is a point of the intersection of the plane P Q with the helicoidal surface. We can obtain in the same manner as many points of this intersection as may be desired. For facility of working, it will be convenient to divide the circumference A B and the space A A' into the same number of equal parts starting from the point A, the points of division of the same level will give the radius analogous to O N, and the horizontal plane analogous to K H, which will determine one point of the desired line. Having the projections of the required intersection, we can obtain it in its true dimensions by describing the plane P Q around its vertical tracing.

To solve the same problem, we can also employ calculation. If we take for the axis of $z$ the axis O I of the surface, for axis of $x$ the direction of the radius O A, and for axis of $y$ a perpendicular radius, designating by $h$ the space A A' of the directing spiral, we shall have for equation of the helicoidal surface,

$$z = \frac{h}{2\pi} \text{ arc tan. } \frac{y}{z} \qquad [1]$$

If $a$ designates the angle of P Q with the axis of $x$, and $b$ the distance $o c$, we shall have for equation of the intersecting plane,

$$z = x \text{ tan. } a + b.$$

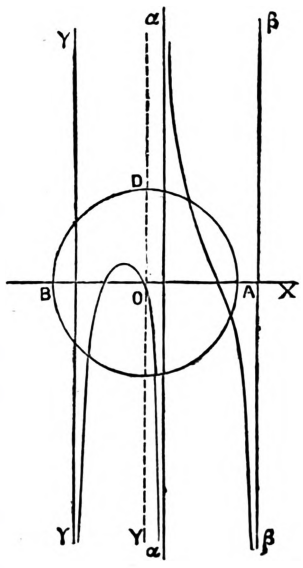
Eliminating $x$ from these two equations, we obtain the equation of the projection of the desired intersection upon the plane of $x y$; that is, $\frac{h}{2\pi} \text{ arc tan. } \frac{x}{y} = x \text{ tan. } a + b$, whence

$$y = x \text{ tan. } \frac{2\pi}{h} (x \text{ tan. } a + b), \qquad [3]$$

which curve we can construct by points. The intersection of the dividing plane with the vertical cylinder, which has this curve for its base, will be the intersection of the same dividing plane with the helicoid surface.

Whichever of the two methods we employ, we shall find that the curve which has for its equation the relation [3], has a form analogous to that indicated in Fig. 1466. It is composed of two branches which have a common asymptote $\alpha\,\alpha$, and two other asymptotes, belonging one to each, $\beta\,\beta$, $\gamma\,\gamma$, all three parallel to the axis of $y$. Other branches and other asymptotes may be obtained by paying attention to the undefined part of the helicoidal surface, which is extended outside the cylinder, whose base is the circle A D B but this consideration is of no value in the question with which we are occupied. If we imagine a vertical cylinder, having for its base the two-branched curve of Fig. 1466, we have seen that its intersection by the cutting plane P Q, Fig. 1465, will be at the same time the intersection of this plane with the helicoidal surface. This intersection will evidently have a form analogous to the curve in 1466.

1466.




For each helicoidal joint it would be necessary to construct an analogous curve, if it were desired to have exactly its intersection with the leading plane. But when the upright section of the arch has a great radius, as is often the case, the intersections of the joints with the leading plane have only a slight curvature, and may, without any appreciable error, be considered as right lines; we can then, in the construction of these lines, profit by a remarkable property of these curves. If from points, such as $b'$ and $c'$, Fig. 1464, where the intersections of the helicoidal joints with the leading plane meet the curve of the intrados E', $c'$, $b'$, F', we draw tangents to these intersections, all these tangents will come together at one point I', situated upon the vertical line of the centre O''. Let us now consider the equation [3]: taking the differentials of the two terms, we obtain

$$y' = \text{tan. } \frac{2\pi}{h} (x \text{ tan. } a + b) + \frac{x\,\delta \frac{2\pi}{h} \text{ tan. } a}{\cos.^2 \frac{2\pi}{h} (x \text{ tan. } a + b)}.$$

Now the ordinate Y of the point, where the tangent of this curve meets the axis of $y$, has for its equivalent $y - y'x$; substituting for $y$ and $y'$ their equivalents, and reducing, we obtain

$$Y = \frac{2\pi \text{ tan. } a}{h} \cdot \frac{x^2}{\cos.^2 \frac{2\pi}{h} (x \text{ tan. } a + b)}.$$

But the equation of the curve gives $\text{tan. } \frac{2\pi}{h} (x \text{ tan. } a + b) = \frac{y}{x}$, whence we get

$$\cos.^2 \frac{2\pi}{h} (x \text{ tan. } a + b) = \frac{x^2}{x^2 + y^2}.$$

Substituting for Y, it follows that $Y = \frac{2\pi \text{ tan. } a}{h} (x^2 + y^2)$.

If we consider in particular the point of the curve which is on the circumference O A, Fig. 1460, the radius of which we represent by $r$, we may write

$$Y = \frac{2\pi \tan.\ \alpha}{h} r^2, \qquad [4]$$

which expression is independent of $b$; that is to say, the distance Y would remain the same if we transposed the intersecting plane P Q in a direction parallel to itself, or, what amounts to the same, if we caused the helicoidal surface to revolve in a direction parallel to its axis. Let us observe now, that all the right lines, which on being described round the cylinder of the intrados, have become the edges of the inner arch, being parallel right lines; these edges of the inner arch are equal spirals. The surfaces of the joints which have these spirals as directing lines are then equal themselves; and they can be made to coincide by causing them to revolve sufficiently in a direction parallel to the axis of the intrados. It follows from this that in place of cutting all the surfaces of the joints by the leading plane, we should obtain the same intersections by cutting only one of them by planes parallel to the leading plane situated at convenient distances from this leading plane. The projections of the curves of intersection upon the plane of the upright section will then also be the same, that is, that to obtain them it is sufficient properly to vary $b$ in the equation [3]. But the distance Y is independent of $b$; hence, if from the points where the different curves which are projections of the intersections of the surfaces of the joints by the leading plane, meet the circumference $a\,b\,d$, Fig. 1464, we draw tangents to those curves, they will come together at a point I, situated on the axis O O′ at a distance from the centre indicated by the expression of Y. But we know that the projection of the tangent of a curve is itself a tangent of the projection of this curve. If then the lines B $b$, C $c$, and so on, Fig. 1464, are the projections of the lines B′ $b'$, C′ $c'$, and so on, upon the plane of the upright section, the tangents at $b$, $c$, and so on, are the projections of the tangents at $b'$, $c'$, and so on. Now the tangents at $b$, $c$, and so on, come together at one point I, then the projecting planes of which these tangents are the tracings, and which are all parallel to the axis O O′, intersect in the direction of a line parallel to this axis passing through the point I. This parallel line meets the leading plane at a point of the vertical of the point O, which is projected at I′ to a distance from O″ equal to $O_1$ I; finally, then, the tangents of the points $b'$, $c'$, and so on, all meet together at the point I′.

The distance O″ I′, or, in absolute value, Y, is easily constructed. From the centre O of the upright section we draw a line parallel to the tracing E F of the leading plane, until it meets at T with the prolongation $a$ F of the line of the spring; and from the point T we draw T Z parallel to the right lines 4′·7, or 3′·6, and so on, which are the development of the edges of the inner arch; $a$ Z will be the desired distance. We have already called $\alpha$ the angle G D A which the leading plane makes with the axis of the intrados; let us now call $i$ the angle $a$ T Z, equal to the angle $a\,a'$ 3 which the developed spiral makes with a line parallel to the axis; there results from this, tan. $i = \frac{2\pi r}{h}$. Now the triangle $O_1$ T $a$ gives T $a$ = $O_1\,a$ tan. $\alpha = r$ tan. $\alpha$, and the triangle T $a\,z$ gives $a$ Z = T $a$ tan. $i = r$ tan. $\alpha$ tan. $i = r$ tan. $\alpha \frac{2\pi r}{h}$, a quantity which is equal to Y in absolute value.

The application of this property to the purpose we are considering is easily made; join the points $b'$, $c'$, and so on, to the point 1′; the prolongations B′ $b'$, C′ $c'$, and so on, of the lines of junction will be the tangents at $b'$, $c'$, and so on, to the intersections of the surfaces of the joints by the leading planes, and may be taken for these intersections themselves under ordinary circumstances where these curves have only an inappreciable curvature.

*To determine the upright joints*, draw right lines such as $\mu\,\nu$, Fig. 1464, perpendicular to the right lines $\rho\,\alpha'$, $\sigma\,\gamma$, and so on, which are the development of the edges of the inner arch. Only a few of these perpendiculars are marked on the sketch. When the figure $\alpha\,\beta\,\beta'\,\alpha'$ is applied to the cylinder of the intrados, the perpendicular in question become arcs of spirals, such as that which is projected at $m\,n$, normal to the edges of the inner arch. Helicoidal surfaces with a square threaded twist having these spirals for directrices are taken for the upright joints. The arch is thus divided into voussoirs by surfaces normal to the inner arch and perpendicular to one another, which is the essential condition of the arrangement of an arch. To obtain an intermediate point of the spiral projected at $m\,n$, we take an intermediate point upon the right line $\mu\,\nu$, for example, that which is found upon the generatrix 3·3′; drawing from this point a line perpendicular to O O′ until we meet with the horizontal projection of the generatrix corresponding to 3·3, we shall have the horizontal projection of the desired point. To get the vertical projections corresponding to $m$ and $n$, it will be sufficient to draw from these points, perpendiculars to the base line until we meet at $m'$ and $n'$ with the lines $c'\,k$ and $b'\,l$, vertical projections of the generatrices, of which $r\,m$ and $s\,n$ are the horizontal projections. As to the intermediate point between $m$ and $n$, we shall draw from this point a line perpendicular to A D, and one perpendicular to X Y; taking that portion of the former which is comprised between A D and the circle $a\,b\,c\,d$, we shall carry it on to the second starting from X Y; we shall thus have an intermediate point upon the projection $m'\,n'$. We may proceed in the same manner for the other upright joints. We have at $\mu\,\nu\,\sigma\,\rho$ the development of the panel of the inner arch corresponding to that portion of the intrados comprised between the joint $m\,n$ and the leading plane. The surfaces of the joints cut the extrados in the direction of spirals having respectively the same space; and this consideration affords the means of obtaining the development of the panel of the extrados which corresponds to the panel $\mu\,\nu\,\sigma\,\rho$ of the intrados. In fact, the two bed-joints and the upright joint which form the limits of the voussoir corresponding to $m\,n\,s\,r$, are cut according to two right lines starting from the points $m$, $m'$, and $n$, $n'$, which, being the generatrices of the two bed-joints, are parallel to the upright section of the intrados and meet the axis O O′. These horizontal projections will then be directed

according to lines perpendicular to O O' drawn from the points $m$ and $n$; and if we develop the extrados, the points where the surface is met by the said generatrices will fall at M and N situated upon the prolongation of the right lines $m\mu$ and $n\nu$. On the other hand, if A U is the development of the leading arc of the extrados, supposed to be obtained in the same manner as for the intrados, the point projected at C' will fall at R, and the point projected at B' will fall at S. The spirals of the extrados which pass through these two points having the same space as those of the intrados which pass through the points $\rho$ and $\sigma$, will give, on development, right lines which will meet together at the same points of the line of $\alpha$ L, starting from which we effected the two developments; that is to say, the spiral corresponding to the point R will give the right line R $\alpha'$, which converges with $\rho\alpha$ to the same point $\alpha'$; and the spiral corresponding to the point S will give the right line S $\sigma'$, which converges with $\sigma\sigma'$ to the same point $\sigma'$ of the line $\alpha$ L. These right lines R $\alpha'$ and S $\sigma'$ will determine the points M and N; and we shall have at M N S R the development of the panel of the extrados corresponding to the panel $\mu\nu\sigma\rho$ of the intrados.

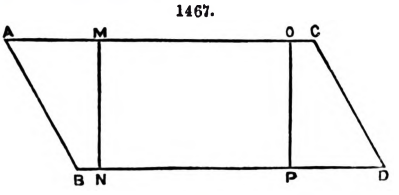
Before proceeding to cut the voussoir, it is still necessary to effect its projection on the plane of the right section. For this, draw from the points $m$ and $n$ perpendiculars to A D until they meet the circumference $a\,b\,c\,d$ at $m_1$ and $n_1$; then from the centre O, take the radii $m_1$ M$_1$, and $n_1$ N$_1$; these will be the projections of the generatrices of joints which pass along the points $m'$, $m'$, and $n$, $n'$. We have already the right lines B $b$ and C $c$ which concur at the point I, the projection of the voussoir under consideration will be comprised between the right lines B $b$ and M$_1$ $n_1$. To apply the draught upon stone, prepare a prism having for its base the curvilinear quadrilateral B $b\,m$, M, and for its height the distance of the points $r$ and $n$ computed parallel to O O'. After having marked upon the two bases the points $b$, $c$, $m_1$, $n_1$, B, C, M$_1$, N$_1$, join the corresponding points by right line, which will be the generatrices of the cylinders of the intrados and the extrados. Upon the concave cylindrical surface apply the flexible panel $\mu\nu\sigma\rho$ in such a way that the point $\nu$ falls at $n_1$, upon one of the bases, the point $\rho$ at $c$ upon the other base, the point $\sigma$ upon the generatrix starting from $b$, and the point $\mu$ upon the generatrix starting from $m_1$. Apply upon the convex cylindrical surface the flexible panel M N S R, in such a way that the point N falls at N, upon one of the bases, the point R at C upon the other base, the point S upon the generatrix starting from B, and the point M upon the generatrix starting from M$_1$. By the help of these two panels trace spirals answering to the right lines $\mu\rho$, $\nu\sigma$, $\mu\nu$, M R, N S, M N, and the elliptical arcs corresponding to the curves $\rho\sigma$ and R S. These two last arcs will determine the plane of the heading face, and allow the face to be cut. As for the spiral joints, they will be cut by using a rule passing along points of reference marked out previously upon the right lines $\mu\rho$ and M R, upon the right lines $\mu\rho$ and N S, and upon the right lines $\mu\nu$ and M N. These points of reference are obtained easily by dividing into the same number of equal parts the right corresponding lines upon which they have to be marked. In the same way all the voussoirs belonging to the leading arcs may be cut.

Supposing the arch to be entirely constructed of ashlar work, all the longitudinal voussoirs might be cut in the same manner. They could also be obtained by a method exactly similar to that used in shaping the stones for the helix of a corkscrew staircase. But more generally the body of the arch is constructed, as has been said, of materials of small dimension, for example, of bricks. The stones which compose this construction are then identical one with another, and to place them properly, spread upon the framework, which is to bear the arch for a time, a layer of plaster forming a cylinder equal to the intrados, upon this layer trace the spirals which form the edges of the inner arch; the distance from one to another is that of the thickness of the stones which are to be used; it only remains to place these latter in the intervals between the spirals, so that the face which is to form the inner arch coincides with the layer of plaster, and they are then united by cement.

Independently of the voussoirs belonging to the head arches, the upper course of the imposts, and the triangular voussoirs marked by the letter $\omega$ in Fig. 1459, named coussinets, are constructed of stone. These coussinets must be firmly fixed in order to resist the thrust of the layers which have a tendency to slip along the bed-joints, considerably inclined towards the springers. For this reason the coussinets are shaped so as to fit in with the stones of the upper course of the imposts. These coussinets have a concave-cylindrical face on the intrados, a convex-cylindrical face on the extrados, a spiral face making part of a bed-joint, and a spiral face forming an upright joint. They are shaped like the heading voussoirs, by means of panels of development of the faces of the intrados and extrados; the figures $a$ 1'' 1 and A 1'' $x$, Fig. 1464, represent these two developments for the first coussinet on the left.

The defect of the helicoidal arrangement lies in the tendency of certain courses to slip outwards: thus the course projected at $b'$ $c'$ $k$ $l$, Fig. 1464, has a tendency to slip towards the back of the arch. To avoid this defect, the helicoidal arrangement may be limited to that portion of the arch comprised between the leading plane and a neighbouring upright section. If, for example, A B and C B, Fig. 1467, represent the horizontal tracing of the leading planes, and M N and O P those of two neighbouring upright sections, the helicoidal arrangement may be employed only for the portions A B N M and C D P O of the arch, and the portion M N P O be arranged as in an ordinary cylindrical arch. The courses which have a tendency to slip outwards, at C and at B, are thus suppressed, or at least reduced to the leading voussoirs. More especially in case the arch is intended to be of great length will it be useful to adopt this arrangement.

1467.

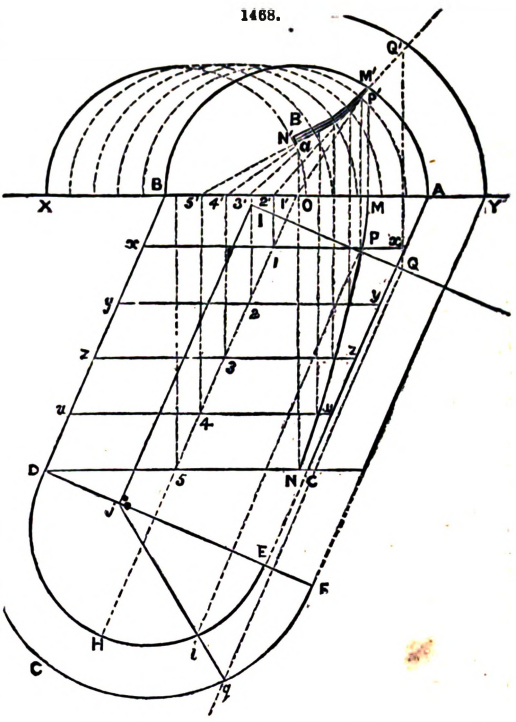



The helicoidal arrangement has also been charged with a tendency in the courses to become twisted when the framework is taken away and before the mortar has acquired a proper consistency. To remedy this, it has been proposed to replace the upright spiral joints by plane joints parallel

to the leading planes. But, on this supposition, it would be preferable to adopt the orthogonal arrangement.

*The Orthogonal Arrangement.*—A line meeting normally all the curves of a series is called their orthogonal trajectory. In the arrangement under consideration the upright joints are vertical planes parallel to the leading planes; these planes cut the intrados according to curves equal to the leading arcs, ellipses for instance; the edges of the suffits are the orthogonal trajectories of these equal curves, and the arrangement ought to be called the arrangement by orthogonal trajectories.

1468.




The projections of these trajectories are constructed in the following manner. Let A C and B D, Fig. 1468, be the spring lines of the arch; we shall take the plane of the spring for the horizontal plane of projection, and the leading plane A B for the vertical plane. To make it more clear, we shall suppose that, as is most frequently the case, the leading curves are circles. Let $x\,x$, $y\,y$, $z\,z$, $u\,u$, be the tracings of planes parallel to the leading planes, and which determine the upright joints; let 0, 1′, 2′, 3′, 4′, 5′, be the centres of circles according to which the intersections of these planes with the intrados are projected. It will be noticed at the outset that each of the required trajectories is projected upon the vertical plane according to a curve which is itself an orthogonal trajectory of the circles whose centres are 0, 1′, 2′, 3′, 4′, 5′. For if we consider by itself one of the required trajectories, at the point where it meets one of the circles $x\,x$, $y\,y$, and so on, its tangent is perpendicular to the tangent of this circle, which is parallel to the vertical plane. Now, when a right angle has one of its sides parallel to one of the planes of projection, we know that it is projected upon this plane at a right angle; the tangent of the trajectory in question then is projected vertically according to the normal of the projection of the circle under consideration, and as we can say the same of all the analogous circles, it results that the projection of the trajectory meets all these circles normally, and that it is in consequence their orthogonal trajectory.

This trajectory of the circles 0, 1′, 2′, and so on, may be determined exactly by calculation. Any one of these circles has for its equation

$$(x - a)^2 + y^2 = R^2, \qquad [5]$$

R designating the radius and $a$ the abscissa of the circle, computed on X Y, starting from any part; for example, from the point A. It is demonstrable, by the differential calculus, that to obtain the orthogonal trajectory of a series of curves, we must state the equation

$$1 + y' \frac{dy}{dx} = 0, \qquad [6]$$

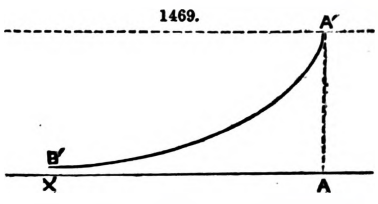
in which $y'$ represents the angular coefficient of the tangent to one of the proposed curves, and must eliminate from this proportion and the general equation of these curves, the variable parameter which belongs to each curve. From the equation [5] we obtain $y' = -\frac{x-d}{y}$, consequently we should have $1 - \frac{(x-d)}{y}\frac{dy}{dx} = 0$; eliminating $d$ from this proportion and the equation [5], and then integrating, we obtain for the equation of the required trajectory

$$x = \log.' \frac{R - \sqrt{R^2 - y^2}}{y} + \frac{\sqrt{R^2 - y^2}}{R} + \text{const.} \qquad [7]$$

We see that all the orthogonal trajectories of the circles 0, 1′, 2′, 3′, and so on, are equal curves, and that having obtained one of them, we shall get all the others by causing the first to revolve parallel to the axis X Y. If, for example, we suppose the arbitrary constant = 0, we shall find for $x$ and $y$ the corresponding values stated in the following Table:—

| Values of $\frac{y}{R}$ | | Values of $\frac{x}{R}$ | |
|---|---|---|---|
| 1 | 0·4 | 0·000 | −0·649 |
| 0·9 | 0·3 | −0·031 | −0·918 |
| 0·8 | 0·2 | −0·092 | −1·310 |
| 0·7 | 0·1 | −0·183 | −1·993 |
| 0·6 | 0·0 | −0·298 | −∞ |
| 0·5 | | −0·460 | |

1469.




These values correspond with a curve of the form indicated in Fig. 1469. If the sections parallel

to the leading planes were ellipses having for semi-axes $a$ and $b$, we should likewise find for the equation of the orthogonal trajectory of their projections upon the vertical plane

$$= \frac{b^2}{a}\left[\log.\frac{b-\sqrt{b^2-y^2}}{y} + \frac{\sqrt{b^2-y^2}}{b}\right] + \text{const.}$$

Instead of having recourse to calculation, we may construct the curve approximately by the property which serves for its definition. For example, let M′, Fig. 1468, be the first point from which we wish to draw an orthogonal trajectory of the circles 0, 1′, 2′, 3′, and so on. If from the point M′ we draw a right line in the direction of the point 0, until it meets the circle 1′; from the point of meeting, a right line in the direction of 1′, until it meets the circle 2′; from the new point of meeting, a right line in the direction of 2′, until it meets the circle 3′; and so on; we shall obtain a broken line M′ $d$, which will differ less and less from the desired curve, in proportion as the sections $x\,x$, $y\,y$, $z\,z$, and so on, are nearer one to another. But it will be a little lower in position than this curve, because its successive sides are normal only to the circle which passes round their upper extremities. If on the contrary we join M′ to the point 1′, arresting the line of junction at the circle 1′, and from the point of meeting draw a right line in the direction of the point 2′, until it meets the circle 2′, and so on, we shall have a second broken line M′ B, which will also differ very little from the desired trajectory, but which will be a little higher in position, because its sides are normal only to the curve which passes round their lower extremities. If, then, we form a broken line M′ N′, by joining the middle points of the arcs of the circles intercepted by the two lines M′$\beta$ and M′ $\alpha$, the line thus traced will differ still less than the two preceding from the curve we wish to obtain.

The projection M′ N′ of the trajectory, which is to serve as the edge of the inner arch, being obtained by one of the above methods, we can easily deduce therefrom its horizontal projection; to do this, from the points at which M′ N′ meets the circles 0, 1′, 2′, 3′, 4′, 5′, we let fall perpendiculars to the base line, terminated at the right lines A B, $x\,x$, $y\,y$, $z\,z$, $u\,u$, C D, horizontal projections of these circles; and joining by a continuous curve the points thus determined, we shall have the projection M N of the trajectory upon the horizontal plane.

We take for the bed-joint corresponding with each edge of the inner arch the left surface formed by the normals to the intrados drawn from the different parts of this line. To obtain the normal to the intrados at any point of the trajectory M N, M′ N′,—at the point P, P′, for example,—it will be observed that this normal is perpendicular to the tangent of the circle $x\,x$; and as the latter is perpendicular to the vertical plane, the normal, for the reason already given, will be projected vertically according to a perpendicular to the tangent at P′ of the circle 1′; that is, according to the normal P′ Q′ to this circle. Besides, the normal to the intrados being included in the plane of the upright section, it will be projected horizontally upon the horizontal tracing of this section, that is to say, perpendicularly to the axis of the arch, or according to P Q perpendicular to A C. We proceed in the same way for all the other normals; the bed-joint is then determined by its rectilinear generatrices.

It is necessary to determine its intersection with the extrados. Let D H E be the upright section of the intrados, and F G that of the extrados, brought down upon the horizontal plane. To get the point of junction of the normal P Q, P′ Q′, with the extrados, we first draw from the point P a parallel to the axis of the arch, until it meets at $p$ with the section E H D; then, after having determined the horizontal tracing I of the normal, we project it at $i$ upon D E; next joining $ip$, we shall have the projection of the normal upon the plane of the right section; prolonging this until it meets at $q$ the curve of the extrados F G; draw from the point $q$ a perpendicular to D E, which will determine the point Q; then a perpendicular to X Y, which will determine the point Q′. Proceeding in the same manner for the other normals, we shall obtain the projections of the intersections of the bed-joint in relation to the surface of the extrados; and the same for the other bed-joints.

Develop, by the ordinary methods, the surface of the intrados and the surface of the extrados with the curves there traced; and we shall have the developments of the panels of the inner arch, and the corresponding panels of the extrados.

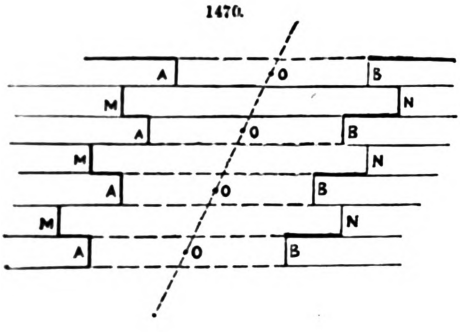
Supposing the arch entirely constructed of ashlar work, each voussoir would be shaped by a method analogous to that explained in treating of the helicoidal arrangement. The four normals which form the angles of the voussoir having been projected upon the plane of the right section, we have the projection of the voussoir upon this plane. Upon this projection is constructed an upright prism, having for height the distance of the two plane joints; for example, the distance of the right lines $x\,x$ and $y\,y$. Upon the concave face of the cylinder we apply the panel of the inner arch, and upon the convex face the corresponding panel of the extrados; the two left joints will be shaped by aid of a rule extended along guiding points marked out beforehand upon each edge of the inner arch, and upon the curved edge which corresponds to the extrados. But more generally, the body of the arch being constructed of rough stones, or of bricks, a layer of plaster is prepared coinciding with the intrados; upon this layer is traced, by the aid of the development of the intrados, the orthogonal trajectories, between which it only remains to arrange the stones intended to form the arch. There will here be a little difficulty additional to that met with in the helicoidal arrangement; the trajectories, although equal one to the other, are not equidistant, and it is necessary in consequence to vary the thickness of the stone employed, according to the distance of the two curves between which it has to be placed. As to the heading voussoirs, they form a sort of arch independent of the principal arch; it results, in fact, from the defective parallelism of the edges of the inner arch that the bed-joints could not be prolonged as far as the leading planes without causing in the size of the heading voussoirs inequalities which would be displeasing to the eye; these voussoirs are then shaped independently, making the bed-joints normal to the leading planes. The shaping of these voussoirs then presents no difficulty; the

plane faces being executed, the cylindrical surfaces are afterwards shaped by means of a rule placed along guiding points chosen beforehand.

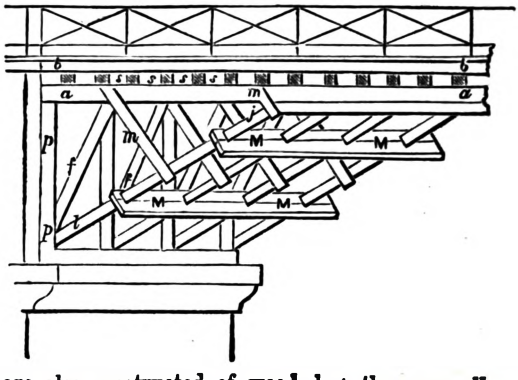
An important simplification has been proposed in the construction of the arch under consideration, which consists in replacing the left bed-joints by the cylindrical surfaces projected by the trajectories upon the leading planes, surfaces which in fact differ very little from the former, and which besides possess the advantage of furnishing only reactions situated in planes parallel to the leading planes, and in consequence not affording any composant perpendicular to these planes; that is to say, not giving rise to a thrust by increasing the opening. When the arch is to be of great length, we can, as shown in Fig. 1467, arrange the portion of the arch comprised between the upright sections M N and O P as an ordinary cylindrical arch, and only employ the orthogonal arrangement for the portions A B N M and C D P O. But in place of using joints running parallel to the heads, we employ vertical planes which converge, some towards the point of junction, the right lines A B and M N, and others towards that of the right lines C D and O P. The edges of the inner arch are the orthogonal trajectories of the vertical sections of the intrados thus obtained; their tracing is necessarily more complicated. This system is that which is called the convergent orthogonal arrangement. Its advantages do not appear to make up for the difficulty of its execution and the ungraceful appearance of the arch.

*Parallel Arches in Echellon.*—Lastly, oblique bridges are formed of a series of upright arches, equal and parallel, but placed one behind another in echellon, as is shown in Fig. 1470, in horizontal projection. These arches are ordinary upright cylindrical arches, but of unimportant length, A B, A B, and so on, whose centres O, O, and so on, are placed on the axis of the oblique arch. They are mutually united by other cylindrical arches M N, M N, whose voussoirs are embayed to a greater or less extent in the thickness of the principal arches. The system is inelegant in appearance.

1470.



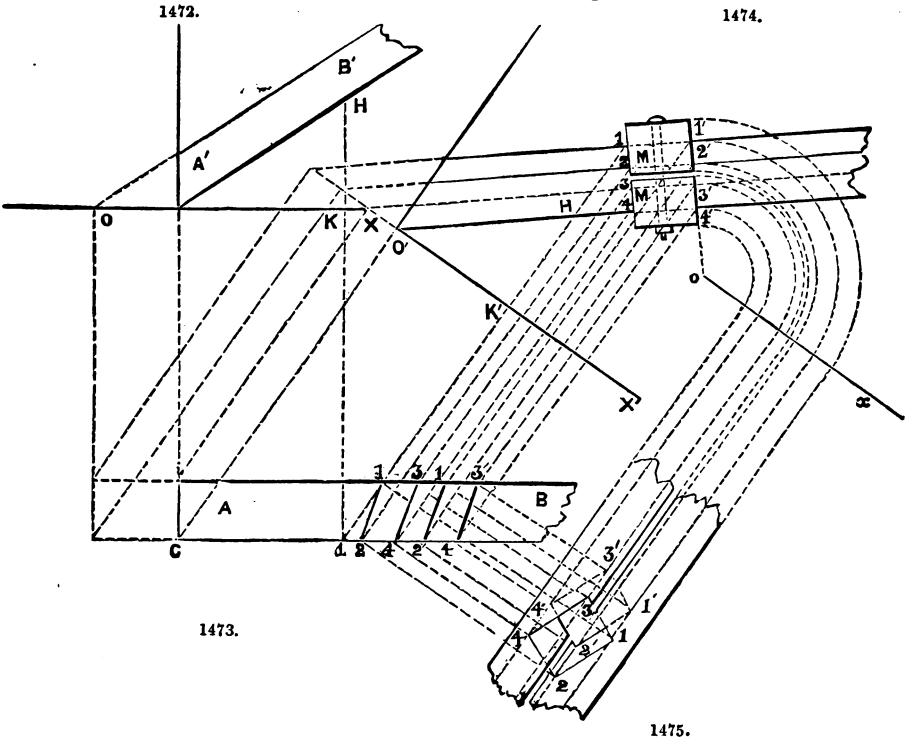

1471.




*Oblique Bridges of Timber.*—Oblique bridges are also constructed of wood, but they are all formed on the principle of the upright arches in echellon; that is, they are composed of a certain number of equal and parallel girders placed in echellon to one another, in such a manner that their homologous points are situated upon right lines parallel to the axis of the bridge, or the direction of the piers. Fig. 1471 represents the vertical projection of a semi-arch of such an arrangement, which is frequently used for the erection of a more permanent structure. Each girder is composed of a horizontal beam *a a*, supported by an upright post *p p*, by a principal rafter *j j*, and a strut *f*. These different parts are united by hanging-braces *m*, *m*. Upon these girders are placed the joists *s s s s*, which support the roadway *b b* of the bridge. In the example given in Fig. 1471, the number of girders is four. The principal difficulty of this mode of construction consists in the method to be adopted to bind together the different girders, in order to form the whole into a perfectly solid system. The method most in use is that of uniting all the girders by horizontal braces M M, which are then parallel to the direction of the piers. But as the rafters pass through the braces in an oblique direction, it is necessary to determine by a draught the apertures to be excavated in these braces. Let A B and A′ B′ be, Fig. 1472 and 1473, the projections of one of these rafters, in relation to a horizontal plane passing through its lowest point O. It is necessary to first fix the transverse dimensions of the braces, by projecting the rafter upon a vertical plane perpendicular to the direction of the piers. Let C O′ be this direction, and let O′ X perpendicular to C O′ be the near ground line. Upon the horizontal projection of the edge which starts from the point C, take any point I, which projects at K upon O X and at K′ upon O′ X′. Prolong the perpendiculars, and take upon the second a length K′ H′ equal to the distance K H, and join O′ H′, which will be the near vertical projection of the edge which touches the point C. The projections of the other edges will be easily obtained from this, in the manner indicated on the figure. Having thus obtained, Fig. 1474, the vertical projections of the rafters upon a vertical plane perpendicular to the direction of the braces, we can determine the upright sections M M of these braces. Mark the points 1, 2, 3, 4, and 1′, 2′, 3′, 4′, where their faces perpendicular to the new vertical plane, meet the edges of the rafter; and project these points, Fig. 1473, upon the corresponding horizontal projections of these edges. We can thus trace the parallelograms 1 2 4 3, and 1′ 2′ 4′ 3′ according to which the rafter penetrates the lateral faces of the braces. Taking, then, in one of these faces a point *o* from which we suppose a horizontal parallel to the direction of the piers, let us imagine the braces to revolve round this horizontal, until the lateral faces of which we have just spoken have assumed a horizontal position, and in this positi n their different points to be projected upon the original horizontal plane of projection. Then, from the summits of the parallelograms 1, 2, 3, 4, and 1′, 2′, 3′, 4′, let fall perpendiculars upon the direction of the edges of the braces. Marking,

Fig. 1475, the intersections of these perpendiculars with the perpendiculars to $o x$ which answer to the same figures, we shall obtain the upper and lower tracings of the apertures we wish to determine, such as will have to be drawn on the faces of the braces when executing these apertures. Only, it must be observed, that as a consequence of the rotatory movement imparted to the braces, it is the upper one which is placed to the right in Fig. 1475, and the lower one which is placed to the left. We may proceed in the same manner for the other apertures, but it will be noticed that they have their faces parallel, and this will much shorten the operation.

1472.



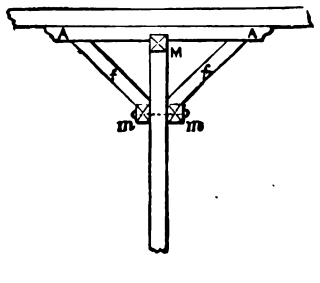

In place of uniting the rafters one to another, the hanging-braces are sometimes connected by horizontal ones. This arrangement would give rise to operations analogous to the preceding. Occasionally a direction differing from the horizontal has been given to the braces uniting the different beams.

*Timber Bridge Construction.*—The roadway of these temporary structures rests upon several girders, generally equidistant. The interval between two consecutive points of support is called a space.

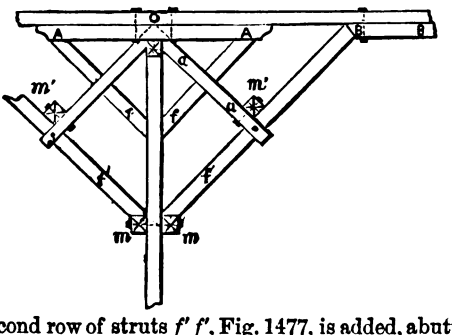
The arrangement of the girders varies considerably; we shall only deal with the systems mostly used.

Where the interval between two consecutive points of support does not exceed 5 mètres, the girders are simply horizontal beams laid upon these supports, and it is on these beams that are placed transversely the cross-beams which sustain the roadway and the pavement. If the interval is to be from 5 to 8 mètres, supplementary beams A A, Fig. 1476, projecting 2 mètres on each side and supported by struts $f f$, are laid upon the piles. Fig. 1476 also shows the heads $m m$ of the horizontal braces uniting the stakes which form the pile, and the head M of the horizontal piece of timber forming the cap of the pile.

1476




1477.




In the case of intervals of 8 to 12 mètres, a second row of struts $f' f'$, Fig. 1477, is added, abutting upon another supplementary beam B, placed in the middle of the interval. If these secondary struts have a length exceeding twelve times their breadth, they are supported by hanging-braces $a a$, which are themselves united from one girder to another by horizontal braces $m' m'$.

For greater intervals several stages of struts or rafters united one to another by vertical hanging-braces may be employed. When the interval is of considerable length, beams bound with iron are employed. The bridge at Wittingen, over the Limmat, forming a single span of 118$^{m}$·90, is cited as the most remarkable instance of this kind of construction: it is composed of several stages of armed beams, united by vertical hanging-braces, and supported by several systems of struts or rafters of different inclinations, the lowest of which is an armed beam.

In the several cases just indicated, the dimensions of a beam are calculated as if it were simply placed upon supports. The total weight for one interval of the roadway and pavement is calculated, and dividing by the number of beams, we have the weight uniformly diffused over the length of a beam. If the bridge is exposed to considerable and varying loads, these must be taken into consideration: such are, upon an ordinary load, the passage of a vehicle representing a weight of 6000 kilos.; or upon a railway, the passage of a locomotive weighing 60,000 kilos., which gives 30,000 kilos. for each beam, as one is ordinarily placed under each rail. Let $a$ be the length of the span, $p$ the weight a linear mètre, P the weight accidentally applied at the middle of the span, we must reconcile the two equations

$$R = \frac{1}{8}\frac{v}{I}(p + p')\,a^2 = \frac{3}{4}b\,h^2\,(p + p')\,a^2 \qquad [1]$$

and

$$R = \frac{v}{I}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,P\,a\right) = \frac{6}{b\,h^2}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,P\,a\right), \qquad [2]$$

calling $b$ the horizontal dimension of the upright section of the beam, and $h$ its vertical dimension. We will take R equal at most to 600,000 for oak, or 800,000 for deal, say, 60 kilogrammes the square centimètre in the first case, and 80 kilogrammes in the second; find the proportion of $h$ to $b$, and deduct $h$ from these two formulæ; the greater of the two values then obtained must be adopted. We can then estimate the weight of the beam to introduce it into $p$, and calculate a nearer value for $h$.

When the same beam forms several spans, or even the total length of a bridge, it is considered as a piece of timber placed upon supports, corresponding to the piers of the abutments. We thus determine the moment of flexion corresponding to each point of support, and next the moment of flexion on any given point of the beam, the maximum of this moment, and by consequence the transverse dimensions of the beam. For the same calculations we deduce the reactions of the supports, and on the other hand the load sustained by these supports, whence we obtain the dimensions of the piles.

The dimensions of the divisions of the bridge must be calculated in the same way as for a portion of timber placed upon a certain number of supports, which are here the beams, loaded with a weight uniformly diffused, and also with a weight applied at the middle of the interval between two beams, representing the movable load caused by the passage of a vehicle. But as this calculation is a very long one, a more rapid, but less exact method is preferred. The dimensions of the portion of the bridge are calculated: 1st, as if the part of this portion comprised between two beams formed an isolated portion placed on two supports; 2nd, as if it were let into the two points of support. In the first case the maximum of the moment of flexion is given by the formula $\mu = \frac{1}{8}p\,a^2 + \frac{1}{4}\,P\,a$; calling $a$ the distance between two beams, $p$ the weight uniformly spread over each portion of the bridge, and P the movable load; in the second case we should have $\mu = \frac{1}{12}\,p\,a^2 + \frac{1}{8}\,P\,a$.

The mean of the values of $\mu$ given by these two formulæ is adopted. When the bridge has to support occasionally only the weight of a wagon not exceeding 4000 kilogrammes, the divisions of the bridge may be 0$^{m}$·50 distant from one another; if the accidental load will be greater, they must be placed nearer together. But it is well to observe that when only a momentary load is in question, wood can be made to support a greater tension than that which we have indicated above, and that it is allowable to increase it then to 100 or 120 kilogrammes the square centimètre.

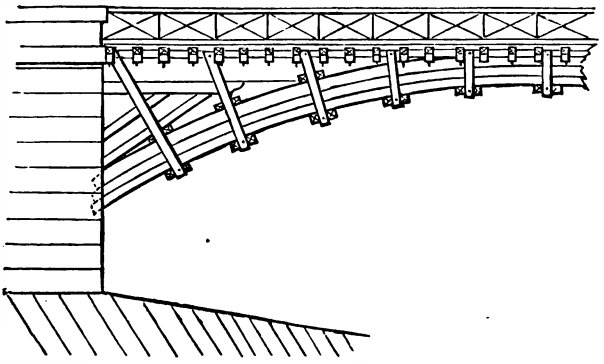
To calculate the dimensions of the struts, suppose each beam placed upon the supports which are formed by the extremities of the piles and the struts, and determine the reactions of these points of support: for struts analogous to that which abuts on the point A, Fig. 1477, we take the resultant of the reaction lengthwise to this piece of timber. It will be necessary that this resultant divided by a transverse section of the strut, should give a quotient equal at most to 60 or 80 kilogrammes the square centimètre, according to the kind of wood employed; for struts such as those abutting on the point B, we should distribute the reaction in the direction of the strut, and in a horizontal direction; and make use of these two resultants, to determine in the same way the transverse dimensions of the strut and the underlying beam.

For bridges of great extent, there has been employed in France for fifty years, a system in which the beams and the roadway are sustained by an arch formed of a certain number of curved rafters, bound together by iron straps, and united to the roadway by hanging-braces in a direction normal to the arch. Fig. 1478 represents one division of the bridge of Ivry-sur-Seine constructed on this plan by M. Emmery. The arch has a chord of 22$^{m}$·50, and a versed sine of 3$^{m}$·48. The roadway rests directly on the crown of the arch, and the beams are hollowed out to accord with this arch. The weight of the roadway is also transferred to the arch by means of braces. The girders are fastened one to another, not only by horizontal braces parallel to the axis of the bridge, but also by horizontal slanting beams which assist in counteracting the effects of the wind on the whole system.

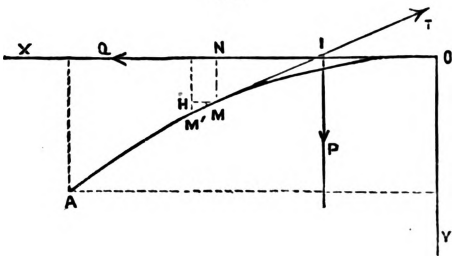
To calculate the transverse dimensions of the arch exactly, it would be necessary to consider the roadway as placed upon the hanging-braces, to determine the reactions of these supports, to

take these in a contrary sense to get the reactions of the braces upon the arch, and determine the normal component of these; we should thus have the forces which act upon the arch independently of its weight. But we can obtain sufficiently approximative results by considering the weight of the roadway as uniformly spread over the horizontal projection of the arch. In the case we are dealing with, the formula $b\,h^2 = \frac{P}{R}\left(\frac{h}{a} + \frac{\rho\,a^3}{4}\right)$ is generally used, in which $b$ is the transverse dimension of the arch in a horizontal direction, $h$ its thickness vertically, P the total weight of the bridge, $\rho$ the mean radius of the arch, $a$ the length of the arc with a radius 1 similar to the arch under consideration, and R a coefficient which it is convenient to take as equal to 300,000.

1478.



1479.




Constructors employ a still more simple method, which gives results sufficiently near. It consists in regarding the proposed arch as the arc of a parabola, loaded with weights proportional to the horizontal projection of its elements. Let O M, Fig. 1479, be a portion of the arch computed from the vertex. Let us take for the axis of $x$ the tangent to the vertex, for the axis of $y$ the axis of the curve. Draw the tangent to M, and by a known property of the parabola this tangent will cut O X in the middle I of the abscissa O N of the point M. Let M′ be a point infinitely near to the point M; draw the horizontal M H and the vertical M′ H. The arch O M is in equilibrium, under the action of the weight P (borne by the arc and which passes through the middle I of O N), of the tension Q exercised at O in the direction O X, and the tension T which is exercised at M in the direction M I. These three forces are then proportional to the three sides of the triangle M I N, or of the triangle M M′ H, which is similar to it. We have then

$$\frac{M'H}{MH} = \frac{P}{Q} \text{ or } \frac{dy}{dx} = \frac{px}{Q},$$

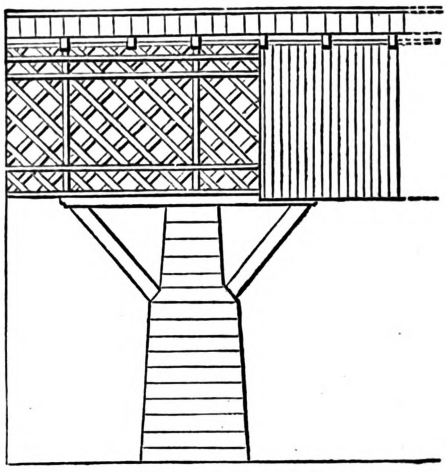
designating by P the weight a linear mètre supported by the arch. Integrating, and observing that for $x = 0$ we should have $y = 0$, we obtain for the equation of the curve $y = \frac{p}{2Q}x^2$. This equation must be completed by the co-ordinates of the spring; if the $a$ is the semichord of the arch and $f$ its versed sine, we should have $f = \frac{p}{2Q}a^2$, whence $Q = \frac{p\,a^2}{2f}$. We shall next have $T = \sqrt{P^2 + Q^2} = \sqrt{p^2x^2 + \frac{p^2a^4}{4f^2}} = p\sqrt{x^2 + \frac{a^4}{4f^2}}$. The maximum of T answers to $x = a$, and has for its value $T = p\,a\sqrt{1 + \frac{a^2}{4f^2}}$. This maximum value will serve to determine the transverse dimensions of the arc.

The arch being supposed to resist only by compression, it will be necessary that the maximum tension T divided by the area of the transverse section should give a quotient at most equal to 60 kilogrammes the square centimètre for oak, or 80 kilogrammes for deal. Calling $b$ the horizontal dimension and $h$ the vertical dimension, we shall have $\frac{T}{b\,h} = 0{\cdot}6$. If we take the millimètre for unity, we shall obtain $b$, and deduce $h = \frac{T}{0{\cdot}6\,b}$.

For some years there have been constructed in America timber bridges on an entirely different system. They were invented to enable railways to pass across considerable streams of water, as we have before stated and illustrated. They are called trellis-bridges, because they have exactly the appearance of trellis-work. Fig. 1480 represents a portion of a bridge of this kind constructed at Richmond, U.S., on the system of Town. The girders, which are $5^m{\cdot}125$ in height, are formed of thick planks arranged trelliswise, applied flat without being let into each other, and joined by oak pegs. They are united by several courses of braces, horizontal as regards the length of the bridge, and by a certain number of vertical braces. Two equal guides are fastened together on each side of the bridge. These two girders leave between them an interval of $3^m{\cdot}20$. They are joined above and below by cross-beams, the intervals between which are filled by diagonal work. Other diagonals, placed vertically according to the transverse sections, complete the protection of this system against the wind. The exterior sides are covered with planks to secure the construction

against the effects of the weather, as is shown on the right side of the figure. This forms a long space of rectangular section.

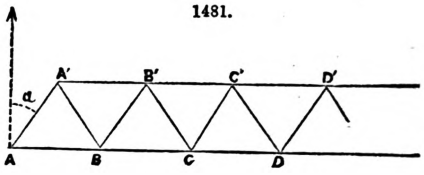
1480.



To appreciate the resistance of such a construction, we may consider each girder as a solid placed upon two supports, loaded with a weight uniformly diffused, and with a load equal to the weight of two locomotives applied in the middle of the span. But as the openings here form about two-thirds of the total volume, it is advisable to reduce to one-third the coefficient R of the resistance, that is, to 20 kilos. a square centimètre for oak, or 27 kilos. for deal. Designating by R' the coefficient thus reduced, by $p$ the weight of the bridge the linear mètre, by P the road applied in the middle of the span, by $a$ the length of the span, by $b$ the total thickness of all the traces in a horizontal direction, and by $h$ the height of each girder, we shall have to apply the formula already used, $R' = \frac{6}{b\,h^2}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,P\,a\right)$.

W. Presse, in his course of "Applied Mechanics," has endeavoured to estimate in a more precise manner the shock supported by each of the pieces composing these girders or beams of trellis-work. He considers first the simplest case to which the system would be reduced, as shown in Fig. 1481, to two courses of inclined rails, A B C D . . . . A' B' C' D' . . . . jointed with inclined ties A A', B B', C C', D D' . . . . on the one hand, and A' B, B' C, C' D, on the other: and he supposes, in the first place, that the beam thus defined supports only a single weight 2 P applied in the centre. It follows at once that the beam receives from the abutment on the pier upon which it rests a vertical reaction P applied at its extremity A. Let $\alpha$ be the acute angle which the inclined rails make with the vertical. There must then be equilibrium between the force P applied at A and the tensions or pressures of the ties A B and A A'; it is then easily seen, by the parallelogram of forces, Fig. 1350, that the rail A A' undergoes a pressure equal to P tan. $\alpha$; and that the rail A A' undergoes a pressure equal to $\frac{P}{\cos.\,\alpha}$. If we next consider the equilibrium of the point A', we find by the same means that the forces exercised in the direction A' B and in the direction of the prolongation of A A' must be equal; and that the tension of A' B' has for its value $2\,\frac{P}{\cos.\,\alpha}$ sin. $\alpha$, or 2 P tan. $\alpha$. The equilibrium of the point B shows, on projecting the forces vertically, that the pressures of A' B and B B' are equal; and on projecting them horizontally, that the tension of B C is equal to P tan. $\alpha + 2\,\frac{P}{\cos.\,\alpha}$ sin. $\alpha$, that is, to 3 P tan. $\alpha$. Adopting the same method with the point B', we find that the pressure of B' C is equal to that of B B', and that the tension of B' C' has for its expression 2 P tan. $\alpha + 2\,\frac{P}{\cos.\,\alpha}$ sin. $\alpha$, that is, 4 P tan. $\alpha$. Continuing thus, we find that all the ties support pressures equal to $\frac{P}{\cos.\,\alpha}$; that the lower horizontal ties support successive tensions expressed by P tan. $\alpha$, 3 P tan. $\alpha$, 5 P tan. $\alpha$, 7 P tan. $\alpha$, and so on; and the upper horizontal ties, tensions expressed by 2 P tan. $\alpha$, 4 P tan. $\alpha$, 6 P tan. $\alpha$, 8 P tan. $\alpha$, and so to the middle of the span. Starting from this point, the same tensions are reproduced in inverse ratio because of the symmetry of the arrangement. If the number of the lower horizontal ties is equal, it is the middle tie which will undergo the greatest tension, and, calling $2n + 1$, the total number of these lines, the maximum tension will be expressed by $(2n + 1)$ P tan. $\alpha$. If the number of the lower horizontal ties is equal, the upper horizontal tie occupying the centre will undergo the greatest tension, and if $2n$ is the number of the lower ties, this maximum tension will be expressed by $2n$ P tan. $\alpha$.

1481.




In the second place, the case in which the trellis-work beam would be loaded with a weight $2p$ at each of the intermediate joints, B, C, D, and so on, of the lower course of braces. If $n$ is the number of these intermediate joints, $np$ represents the vertical reaction which is exercised at the point A. Considering, step by step, the equilibrium of the upper and lower points of junction, we arrive at the following conclusions:—

1st. The sides parallel to A A' undergo pressures, having successively for their value $\frac{np}{\cos.\,\alpha}$, $\frac{(n-2)\,p}{\cos.\,\alpha}$, $\frac{(n-4)\,p}{\cos.\,\alpha}$, $\frac{(n-6)\,p}{\cos.\,\alpha}$, and so on.

2nd. Two inclined ties abutting at the same point, are, the one, compressed, the other extended, by the same intensity.

3rd. The pressures of the upper ties are represented by the values, $2np$ tan. $\alpha$, $4(n-1)p$ tan. $\alpha$, $6(n-2)p$ tan. $\alpha$, $8(n-3)p$ tan. $\alpha$, and so on.

4th. The tensions of the lower horizontal ties are expressed by $np$ tan. $\alpha$, $[n + 2(n-1)]p$ tan. $\alpha$, $[n + 4(n-2)]p$ tan. $\alpha$, $[n + 6(n-3)]p$ tan. $\alpha$, and so on.

Calling $i$ the position of a horizontal tie in each of these series, we have for the pressure of an upper tie, $2i(n - i + 1)\,p$ tan. $\alpha$, and for the tension of a lower tie,

$$[n + 2(i - 1)(n - i + 1)]\,p \text{ tan. } \alpha.$$

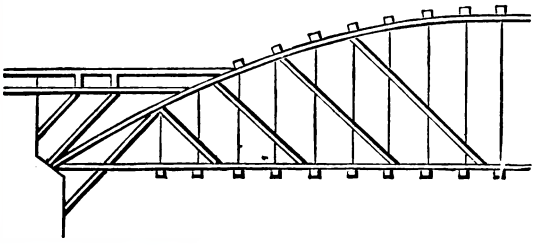
The maximum of the first expression answers to $i = \frac{n+1}{2}$, and that of the second to $i = \frac{n+2}{2}$; if these terms are not integers, the maximum will not be produced exactly, but approximately, although $n$ may be a large number, as is ordinarily the case. We find the value of the maximum to be $\frac{1}{2}\,p$ tan. $\alpha\,(n+1)^2$ in the first case, and $\frac{1}{2}\,p$ tan. $\alpha\,[(n+1)^2 - 1]$ in the second. So that, calling N the number of times that A B is contained in the length of the span, the maximum of pressure or tension of the horizontal ties is expressed by $\frac{1}{2}\,p\,N^2$ tan. $\alpha$.

There have been constructed in Bavaria timber bridges differing from the American system only in that the joints of all the pieces of woodwork are united by cast-iron sockets, and the girders enter the abutments, hollowed out for this purpose.

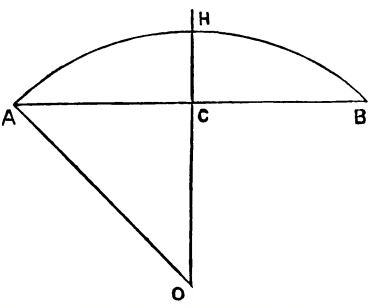
In America there has also been applied another system founded on the use of curved arches. Such is the bridge at Trenton over the Delaware, partially represented in Fig. 1482. The girders are five in number; in each, the principal part is an arc of a circle formed of eight planks superposed; it rests at its extremities upon the piers, and supports the roadway by means of suspending iron bars. The arch is, besides, united to the roadway by pendant ties inclined at an angle of 45°. All the woodwork is covered by a roof, and sheltered laterally by planks. The arches of two successive spans abut against each other by means of woodwork raised upon the pier and elevated to two-thirds of the height of the arches.

Lastly, there has been constructed at Liep, York county, a bridge of the same kind, but in which the roadway, in place of forming the chord of an arc, is placed at mid-height between the chord or the vertex; so that the roadway is suspended underneath the upper portion of the arch, whilst it rests upon its lower portion. This system, in which the bridge forms a girder, appears to offer more resistance.

1482.



1483.




*Stone Bridges.*—After the water-way has been fixed, we have to determine the dimension and the form of the arches.

There is a very simple relation between the span of a segmental arch, its height or versed sine, and the radius of the circle to which the arc belongs. If $2c$ represents the span, or the chord A B, Fig. 1483, of the arc, $f$ the versed sine H C, and R the radius O A, the semichord A C being a mean proportional between the two segments of the diameter to which it is perpendicular, we have

$$c^2 = f(2R - f), \text{ whence } R = \frac{c^2 + f^2}{2f}. \qquad [1]$$

If we wish to have the semi-arc A H in degrees, or the angle of the centre A O H, we observe that it has for its sine the proportion $\frac{AC}{AO}$ or $\frac{c}{R}$; designating the angle by $\alpha$, we have then

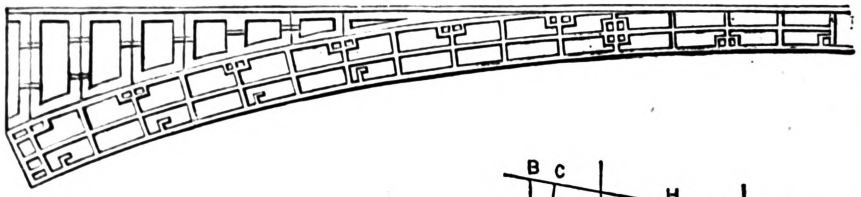
$$\sin.\ \alpha = \frac{2fc}{c^2 + f^2} = \frac{2\frac{f}{c}}{1 + \frac{f^2}{c^2}} \qquad [2]$$

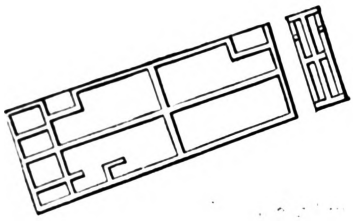
It is not usual to give to the proportion $\frac{f}{c}$ a lower value than $\frac{1}{4}$, which supposes a height equal to $\frac{1}{8}$ of the span, and gives sin. $\alpha = 28°\ 4'\ 20''$, or thereabouts. However, in exceptional cases, this proportion has sometimes been reduced to $\frac{1}{5}$ or $\frac{1}{6}$.

The bridge of Solferino is an example of the form adopted in the early construction of iron bridges. The arches, Fig. 1484, have a span of 40 mètres, and a height of $4^m \cdot 02$. They are formed of cast-iron voussoirs, of open work in the leading arches and solid in the intermediate. The figure, 1485, represents the elevation and the transverse section of the first voussoir of an intermediate arch. It will be seen that the section represents a double T, with a central rib. The pediment, that is to say, the space comprised between the arch and the roadway, is filled up by open-work plates of a trapezoidal form. Fig. 1486 represents one of these plates.

The girders are united one to another by three systems of cross-joints, placed, some above the ribs of the intrados, others below it, and others upon the ribs which form the crown of the pediment. These latter cross-joints, at a distance of $1^m \cdot 30$, also serve to sustain arches of brick and Roman cement, upon which the roadway and the side-walks are erected. In this system of arches formed of

1484.

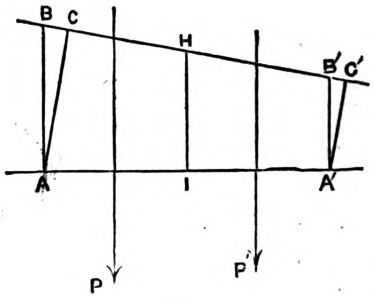




1485.



1486.

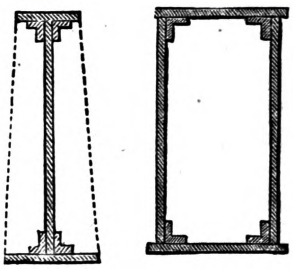



1487.

voussoirs, the casting is only subject to compression; the only portions exposed to extension are the cross-joints, but as they are few in number they may be executed in wrought iron. The pressures to which the voussoirs are subject can be calculated as for stone arches. But the inequalities of the load are of much greater importance here than in stone bridges. Supposing that one half of the span bears the maximum load of 400 kilos. a square mètre, whilst the other only supports its own weight, we can determine on this hypothesis the direction and intensity of the thrust on the key. Let P and P', Fig. 1487, be the weights supported by the two halves, H the point of application of the reaction N of the two halves of the arch, and B C the oblique direction of this reaction. We let fall from the springs A and A', upon this direction, the perpendiculars A C and A' C', and erect the verticals A B and A' B'. Let $p$ and $p'$ be the distances of the forces P and P' from the points A and A'. We shall have for the equilibrium of the first half of the arch the formula $N \times AC = Pp$, and for the equilibrium of the second half $N \times A'C' = P'p'$, whence dividing member by member, $\frac{AC}{A'C'} = \frac{Pp}{P'p'}$. But the triangle A B C and A' B' C' being similar, the first term may be replaced by the proportion of A B to A' B', which gives $\frac{AB}{A'B'} = \frac{Pp}{P'p'}$, whence $\frac{AB}{AB + A'B'} = \frac{Pp}{Pp + P'p'}$. Now, calling H the height I H, we have $AB + A'B' = 2H$, consequently there results $AB = 2H \frac{Pp}{Pp + P'p'}$, from which we can obtain the direction of the force N, next the distance A C, and ultimately the intensity of the thrust N.

The most remarkable example of a bridge with straight iron beams is the **Britannia Bridge**, constructed in 1850 over the Menai Straits, by Robert Stephenson, on the Chester and Holyhead Railway. This bridge traverses an arm of the sea at 33 mètres above high water, by means of four spans, of which two are not less than 140 mètres long. This bridge has the form of a long tube, with a rectangular section of $9^m \cdot 144$ in height by $4^m$ 50 in breadth. Its upper casing wall is itself formed of eight equal tubes, fastened one to another, of a square section of $0^m \cdot 533$ a side, and its flooring is formed of six similar tubes $0^m \cdot 533$ high by $0^m \cdot 711$ wide. The lateral walls are solid, and united, both above and below, by triangular brackets $1^m \cdot 22$ high by $0^m \cdot 533$ wide. Since the completion of this work, about which an immense amount of nonsense has been written, bridges with beams of iron plating have multiplied considerably. In bridges of small dimensions the beam is composed of a long plate of sheet iron, made fast at top and bottom by angle-iron; Fig. 1488 gives the section of this beam. It is strengthened from distance to distance by transverse plates having the same height as the beam, and towards the top the same width as the upper plate, while towards the bottom they are of greater width. This form is represented by the dotted lines on Fig. 1488. In the more important bridges, the beam is a tube with a rectangular section, formed of four plates of iron held together by angle-iron. Fig. 1489 is the section of a beam of this kind. The arrangement of these beams has been varied in many ways, those just described are the most generally used. On railways, beams analogous to that of Figs. 1488, 1489. are ordinarily placed above the roadway which rests on the lower ribs; these beams are three in number, and the trains pass along the spaces between them. It follows, when the bridge is of large dimensions and the beams consequently of

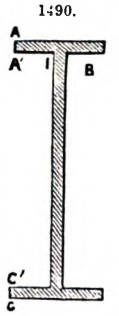
1488. 1489.



great height, that the prospect is completely shut out when passing over rivers, that is, at the most picturesque parts of the way. To obviate this inconvenience, the German engineers have endeavoured to replace the solid walls of the beams by walls of trellis-work; but this system, in which one of the sets of bars forming the trellis is elongated while the other is compressed, does not afford sufficient solidity.

To determine the transverse dimensions of straight beams, they are considered as prismatic bodies placed upon two supports, loaded with a weight uniformly diffused, and with a load applied at the centre. If $p$ designates the weight a mètre uniformly diffused, P the load applied at the middle of their extent, $x$ the length of this, R the limit of tension which must not be exceeded, $h$ the height of the bridge, and I the moment of inertia of its upright section in relation to the horizontal drawn in this section through its middle, or, more exactly, through its centre of gravity, we shall have to apply the empirical formula $R = \frac{\frac{1}{2}h}{I}\left(\frac{1}{8}pa^2 + \frac{1}{4}Pa\right)$. But it is necessary to observe here that, as in the case of timber bridges, if the load is the weight of two locomotives crossing at the middle of the interspace, as this is an exceptional load, we may admit that the plates, in place of only having to support, as ordinarily supposed, about $\frac{1}{10}$ of the tension corresponding to its limit of elasticity, momentarily supports $\frac{1}{5}$; that is, in place of taking for R 6 kilos. a square mètre, we should take 12 kilos.

1490.




In arched metal bridges, the beams which sustain the flooring are ordinarily of cast iron, in the shape of a double T. But sometimes it is required that the resistance should be the same in all the transverse sections, at least over a certain extent, starting from the key. To this end, the distance between the internal edges of the ribs is made to vary. If, for example, $h$ stands for the distance between the ends A and C, Fig. 1490, $b$ the distance between the points A and B, $h'$ the distance between the points A′ and C′, and $b'$ twice the distance A′ I, $h'$ is made to vary in such a manner that the resistance caused by the weight uniformly diffused may be the same for each section within certain limits.

Let $p$ be the weight uniformly diffused, and $a$ the length of the interspace; each point of support will exercise a reaction equal to $\frac{1}{2}pa$; the moment of the forces which act upon this space, from the point which has for its abscissa $x$, computed from one of the extremities as far as the other extremity, will have for value $\mu = p(a-x)\frac{1}{2}(a-x) = -\frac{1}{2}pa(a-x)$; or $\mu = -p(ax - x^2)$.

The moment of inertia of the section in relation to the horizontal passing through its centre of gravity is besides, according to an empirical formula, $I = \frac{1}{12}(bh^3 - b'h'^3)$; finally, the ordinate of the most distant rib from the axis is $v = \frac{1}{2}h$.

Calling R the limit of tension not to be exceeded, we shall then have, taking only the absolute value of $\mu$, $R = \frac{v\mu}{I} = \frac{bp(ax - x^2)}{bh^3 - b'h'^3}$, a formula which will give the values of $h'$ corresponding to the values of $x$. But as it is not necessary that the thickness A A should be less than the thickness of the vertical nucleus, as soon as $h'$ has attained the value that is given for this thickness, we cease adding to $h'$, and diminish $h$ as far as a limit fixed beforehand. On the Auteuil railway, for instance, we have, according to M. Claudel,

$$p = 1600^k, h = 0^m{\cdot}60, b = 0^m\ 28, b' = 0^m{\cdot}26, a = 8 \text{ mètres};$$

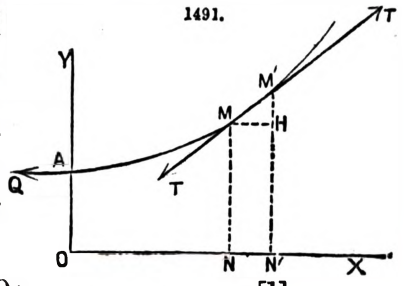
and, taking R, for want of better knowledge, as equal to 6,000,000, we find the value of $x$ corresponding to the key, that is for $x = \frac{1}{2}ah = 0^m{\cdot}52$, which will give $0^m{\cdot}08$ for the thickness of the two united ribs, or $0^m{\cdot}04$ for each of them. We find that for $x = 1^m{\cdot}44$ (about), the thickness of each rib is reduced to $0^m{\cdot}02$, which is the thickness of the nucleus; $h$ and $h'$ are then diminished by an equal quantity without decreasing the thickness of the rib, until we reach $h = 0^m{\cdot}40$, the limit of height fixed beforehand.

The cross-bars are also ordinarily of a double T section. On the Auteuil railroad we have $a = 2^m$, $h = 0^m{\cdot}30$, $b = 0^m{\cdot}20$, $b' = 0^m{\cdot}188$, whence we deduce $0^m{\cdot}014$ for the thickness of the nucleus and the ribs.

*Suspension Bridges.*—The first consideration in suspension bridges is to determine the geometrical position of the angles of the polygon formed by the points of attachment of the suspending rods. It will be observed, first, that each couple of rods corresponding with the two sides of the roadway may be considered as bearing half the weight of each of the two interspaces comprised between the couple of rods and the preceding or following. If the rods are equidistant, they will consequently sustain equal weights. If the rods were infinite in number and infinitely close to one another, each couple would sustain an element of the roadway, and any given portion of the chain would sustain a weight proportioned to its horizontal projection. On this hypothesis it is easy to perceive that, disregarding the weight of the rods, the chain would assume the form of a parabola to the vertical axis, the equation of which is easily ascertained. Let A, Fig. 1491, be the lowest point of the chain. At this point is exercised a horizontal tension which we will represent by Q. Let us take for the axis of $y$, the vertical of the point A, and for the axis of $x$ a horizontal O X drawn at the height of the roadway. Let M and M′ be two points of the chain infinitely close to one another · let T be the tension of the chain at the point M, a force

which is applied in the direction of a tangent at this point. If $a$ designates the angle of this tangent with the horizon, the horizontal and vertical components of T will be T cos. $a$ and T sin. $a$. Passing from the point M to the point M', these components will become T cos. $a + d$, T sin. $a$, and T sin. $a + d$, T sin. $a$.

1491.




Let $2p$ be the weight a lineal mètre of the bridge, $2p\,dx$ will be the weight of an element of this bridge, and $p\,dx$ will be the weight of the portion N N' of the bridge supported by a rod jointed at the middle of the element M M'. This element being in equilibrium under the action of this weight and of the two tensions already considered, we shall have, by taking the sum of the horizontal components (T cos. $a + d$, T cos. $a$) — T cos. $a = 0$, or $d$, T cos. $a = 0$, whence

$$\text{T cos. } a = \text{const.} = \text{Q}; \qquad [1]$$

and taking the sum of the vertical components,

$$(\text{T sin. } a + d,\ \text{T sin. } a) - \text{T sin. } a - p\,dx = 0, \text{ or } d,\ \text{T sin. } a = p\,dx,$$

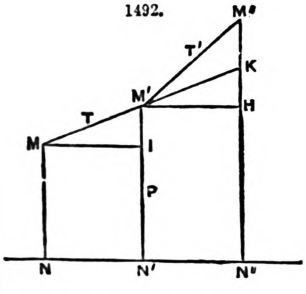
and substituting for T its value $\frac{\text{Q}}{\text{cos. } a}$, $d\,\text{Q tan. } a = p\,dx$, or $\text{Q}\,dy' = p\,dx$, calling $y'$ the angular coefficient of the tangent at M. Integrating and observing that the point A is the lowest point, we have $y' = 0$ for $x = 0$; we obtain $\text{Q}\,y' = px$, or $dy = \frac{p}{\text{Q}}\,x\,dx$. Integrating afresh and designating by $y$, the ordinate of the point A, we find

$$y - y_0 = \frac{p}{2\,\text{Q}}\,x^2, \qquad [2]$$

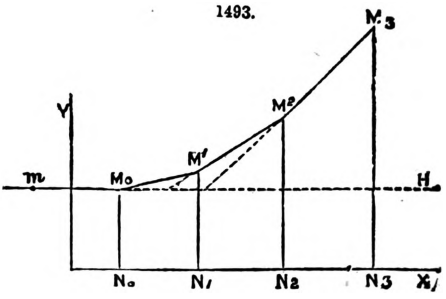
the equation of a parabola which has for axis the axis of $y$, $d$ being employed as the differential sign.

Without supposing the rods infinite in number, if we suppose them equidistant, as is ordinarily the case, and disregarding their weight, we may demonstrate by very slight consideration that the angles of the polygon formed by the chain are upon a parabola. Let M, M', M'', Fig. 1492, be three consecutive points of the chain; let T and T' be the tensions of the sides M M' and M' M'', and P the weight supported by the rod M' N'. The point M' being in equilibrium under the action of these three forces, the sum of their horizontal components is equal to 0; that is to say, the horizontal projection of the tension of any given side is a constant quantity; we will designate it as above, by Q. Produce the side M M' as far as K; the three forces T, T', and P, will be proportional to the three sides of the triangle M' M'' K, which are respectively parallel to them. If then we represent the tension T by the side M M', or by its equal M' K, the tension T' will be represented by M' M'', and the weight P by M'' K. Now the weight sustained by each rod is a constant quantity, since the rods are equidistant; the length M'' K is then also constant. Draw the horizontals M I and M' H. The length M' I or its equal K H being the primary difference of the ordinate M N; that is to say, the difference between M' N', and M N, and M'' H, being the primary difference of the ordinate M' N', that is the difference between M'' N'' and M' N', the length K, which is the difference between these two primary differences, is nothing else than the second difference of M N. The centre of curvature of the points of the chain has then this property, that the second difference of the ordinate is constant; it is then a curve, the equation of which is in the form $y = a + bx + cx^2$, that is, it is a parabola, whose axis is parallel to the ordinates.

1492.




1493.




Finally, still disregarding the weight of the rods, whatever may be the successive distances of the rods one from the other, the consecutive points of attachment of the chain are always upon a parabola. Let $\text{M}_0$, $\text{M}_1$, $\text{M}_2$, $\text{M}_3$, . . . . Fig. 1493, be the consecutive points of the chain; $x_0$, $y_0$, $x_1$, $y_1$, $x_2$, $y_2$, . . . . their co-ordinates in relation to two rectangular axes, the one vertical passing through the middle of the horizontal side $m\,\text{M}_0$, and the other horizontal; $\text{P}_0$, $\text{P}_1$, $\text{P}_2$, $\text{P}_3$, the weights supported by the corresponding rods; $\text{T}_1$, $\text{T}_2$, $\text{T}_3$, . . . . the tensions of the consecutive sides; Q their common horizontal projection. It is sufficient, in fact, to consider the equilibrium of any given apex and make equal to 0 the sum of the horizontal projections of the forces acting upon it, to see that all these tensions have horizontal projections equal in absolute value. Let us consider the equilibrium of the point $\text{M}_0$; the weight $\text{P}_0$ applied at this point has for its expression

$$\text{P}_0 = p\left(x_0 + \frac{x_1 - x_0}{2}\right) = \frac{1}{2}\,p\,(x_1 + x_0), \qquad [3]$$

designating by $p$ the weight a linear mètre sustained by the chain, which is the half of the weight per linear mètre of the roadway. Making equal to 0 the sum of the horizontal projections of the forces Q, T, and $P_0$, we obtain

$$Q = T_1 \cos. M_1 M_0 H = T_1 \frac{x_1 - x_0}{M_0 M_1}$$

Making equal to 0 the sum of the vertical components of the same forces, we find

$$\frac{p}{2}(x_1 + x_0) = T_1 \sin. M_1 M_0 H = T_1 \frac{y_1 - y_0}{M_0 M_1}.$$

If we divide term by term the two proportions just established, we obtain

$$\frac{1}{2}\frac{p}{Q} x_1 + x_0) = \frac{y_1 - y_0}{x_1 - x_0}, \text{ whence } y_1 - y_0 = \frac{p}{2Q}(x_1^2 - x_0^2). \qquad [4]$$

If we consider the equilibrium of the point $M_1$, we shall find in the same way

$$Q = T_2 \frac{x_2 - x_1}{M_1 M_2} \text{ and } \frac{p}{2}(x_2 + x_1) = T_2 \frac{y^2 - y}{M_1 M_2},$$

whence dividing term by term,

$$\frac{p}{2Q}(x_2 + x_1) = \frac{y_2 - y_1}{x_2 x_1}, \text{ or } y_2 - y_1 = \frac{p}{2Q}(x_2^2 - x_1^2). \qquad [5]$$

Applying the same method to all the other points, we shall obtain analogous relations; and if $x_{n-1}$, $y_{n-1}$, and $x_n$, $y_n$ represent the co-ordinates of any two given consecutive points, we shall have

$$y_n - y_{n-1} = \frac{p}{2Q}(x_n^2 - x_{n-1}^2). \qquad [6]$$

Adding term to term all the relations thus obtained, and reducing, we

$$y_n - y_0 = \frac{p}{2Q}(x_n^2 - x_0^2),$$

so that by suppressing the index $n$ we have for any given point of which $x$ and $y$ are the co-ordinates,

$$y - y_0 = \frac{p}{2Q}(x^2 - x_0^2); \qquad [7]$$

this is the equation of a parabola whose axis is vertical, and which has for its vertex the point of the axis of $y$ having for its ordinate $y_0 - \frac{p}{2Q} x_0^2$.

If the chain had no horizontal side, we should make the $y$ axis pass through the lowest apex $M_0$; we should then have $x_0 = 0$, and applying the same method, we should find the equation of the parabola to be

$$y - y_0 = \frac{p}{2Q} x^2. \qquad [8]$$

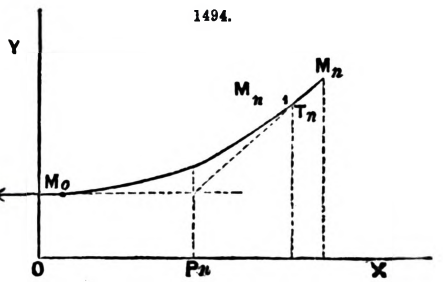
Having the equation of the curve, we can easily deduce from it the horizontal component Q of the tensions of the sides. In fact, the point at which the chain meets the vertical, elevated at the extremity of the roadway, may be considered as a point of the chain; now this point is always given. If the chain is symmetrical with relation to the lowest point, the co-ordinates of this imaginary point of attachment are the semi-span $a$ of the bridge, and the height $h$ of this point above the axis $x$; we should then have, in the case of the formula [7],

$$h - y_0 = \frac{p}{2Q}(a^2 - x_0^2), \text{ whence } Q = \frac{1}{2} p \frac{(a^2 - x_0^2)}{h - y_0}.$$

In the case of the formula [8], we should have

$$Q = \frac{1}{2} p \frac{a^2}{h - y_0}.$$

1494.




Thus, by assuming the supposed point of attachment, and the point $M_0$, we determine the ordinate of a point of the chain corresponding with a given abscissa, and consequently the point corresponding with a given rod, as well as the horizontal tension of the chain.

The actual point of attachment is always situated beyond the point which we have called the imaginary point of attachment.

It is easy to deduce from the preceding the tension of a given side of the polygon formed by the chain. Let $M_{n-1}$ and $M_n$, Fig. 1494, be two given consecutive points, and $T_n$ the tension of the side $M_{n-1} M_n$. The portion of the chain comprised between the point $M_0$ and the point $M_{n-1}$ bears the weight of the roadway comprised between the axis of $y$ and the vertical passing through the middle of $M_{n-1}$, $M_n$; this weight has then the value

$$P_n = p\left(x_{n-1} + \frac{x_n - x_{n-1}}{2}\right) = \frac{1}{2} p (x_{n-1} + x_n).$$

This portion of the chain is in equilibrium under the action of its weight, and of the forces Q and $T_n$; calling $\alpha_n$ the angle of the side $M_{n-1} M_n$ with the horizon, and making equal to 0 the

sum of the horizontal components and that of the vertical components of these three forces, we obtain $T_n \cos. a_n = Q$, and $T_n \sin. a_n = P_n$, whence, squaring, adding, and extracting the square root:

$$T_n = \sqrt{Q^2 + P_n^2}. \qquad [9]$$

This tension increases with $P_n$; thus the maximum of tension is placed on the last side. In order to calculate it more easily, we may suppose that the lowest point of the chain is the vertex of the parabola, which is to place it in the case of the formula [8]; and if we call $b$ the difference $h - y_0$, or the height of the point of attachment above the lowest point, we have

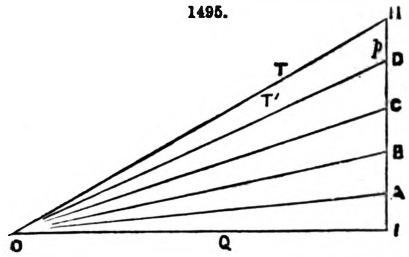
$$Q = \frac{1}{2} p \frac{a^2}{b}.$$

Besides, we have then $P = pa$; calling T the maximum tension, it follows that

$$T = \sqrt{p^2 a^2 \frac{1}{4} p^2 \frac{a^4}{b^2}}, \text{ or } T = pa \sqrt{1 + \frac{a^2}{4 b^2}}. \qquad [10]$$

The horizontal tension and that of the different sides of the chain may also be determined geometrically when we know the inclination of the last side. To make this clear, we will take the case where there is a horizontal side. Upon a vertical of indefinite length let us take the lengths I A, A B, B C, . . . . D H, Fig. 1495, proportional to the successive weights supported by the different rods; that is to say, to half the sum of the weights of the two adjacent divisions of the bridge. From the point I draw a horizontal, and from the extreme point H a right line, having the inclination given by the last side of the chain. These two right lines meet at a point O; draw O A, O B, O C, . . . . O D. The right line I H, representing the weight borne by the rods O I, will represent the horizontal tension Q, and the lines O A, O B, O C, and so on, will represent the tensions of the successive sides of the chain; O H will represent the tension of the last side, which is the maximum tension. If we first consider the portion of chain comprised between the first rod and the last, we see that it is in equilibrium under the action of the horizontal tension Q of the tension T of the last side, and of the weight P of the roadway borne by these rods. Now, these three forces being parallel to the three sides of the triangle O I H, they are proportional to these sides, and since P is represented by I H, it follows that Q is represented by O I, and T by O H.

1495.




Let us now consider the point of attachment of the last rod; it is in equilibrium under the action of the weight $p$, suspended to the rod, of the tension T of the last side, and the tension T' of the preceding side. Now, the two former forces being represented in magnitude and in direction by the two sides D H and O H of the triangle O D H, the third force T' must be represented in magnitude and in direction by the third side O D of this triangle. We should thus demonstrate step by step that O C, O B, O A, and so on, represent in magnitude and direction the successive tensions of the other sides. An analogous mode of reasoning would be employed in case there were no horizontal side. In both cases the force Q is the horizontal projection common to all the tensions.

It is necessary to determine the length of the chain. To obtain this, we might calculate successively each of its sides by means of the co-ordinates of its extremities. But this method is a very laborious one; and we can obtain a sufficient approximation by substituting for the polygon the circumscribed parabola, of which we have the equation. We take for this the equation [8], in which we suppress $y_0$, which amounts to making the $x$ axis pass through the lowest point; we thus get $y = \frac{p}{2Q} x^2$, or, replacing Q by its value, $\frac{1}{2} p \frac{a}{b}$,

$$y = b \frac{x^2}{a^2}. \qquad [11]$$

Calling $s$ the length of the arc of the curve computed from the vertex, we have

$$ds = dx \sqrt{1 + y'^2};$$

but $y' = 2b \frac{x}{a^2}$, consequently $ds = dx \sqrt{1 + \frac{4 b^2 x^2}{a^4}}$.

In the ordinary application, $b$ is small in comparison with $a$; besides, $x$ is at the most equal to $a$; the fraction under the radical is then very small; and we may, without perceptible error, add under the radical $\frac{4 b^4 x^4}{a^8}$; the quantity under the radical then becomes a perfect square number, and extracting the root, we obtain $ds = dx \left(1 + \frac{2 b^2 x^2}{a^4}\right)$.

Integrating, and observing that for $x = 0$ we should have $s = 0$, we find

$$S = x + \frac{2}{3} \frac{b^2 x^3}{a^4}$$

and for $x = a$,

$$s = a + \frac{2}{3} \frac{b^2}{a} = a \left(1 + \frac{2}{3} \frac{b^2}{a^2}\right), \qquad [12]$$

which is the length of the parabola from the lowest point up to the point which corresponds with the extremity of the roadway.

This length of the chain is its absolute length under the action of the load which it supports; it is greater than its original length $s_0$ by the elongation produced by tension. Let $\theta$ be a mean between the maximum tension calculated above, and the horizontal tension Q; the elongation of iron a linear mètre being 0·00005 mètre for a tension of 1 kilogramme a square millimètre of the section, calling $\omega$ the section of the chain expressed in square millimètres, $s - s_0 = s_0 \frac{\theta}{\omega} 0^{m}\cdot 00005$,

whence $s_0 = \frac{s}{1 + \frac{t}{\omega} 0\cdot 0005}$. The length $s$ will vary with the temperature; the coefficient of the expansion of iron, roughly estimated, is 0·0000122, so that passing from 0 to the temperature $t$, the length $s$ becomes $s' = s(1 + 0\cdot 0000122\, t)$. From this results an increase of the versed sine, which it is necessary to know how to calculate. Now, if in the formula [12] we allow $s$ and $b$ to become variables and differentiate, we have $ds = \frac{4b}{3a} db$. For in considerable expansions we may admit that the final increments of $s$ and $b$ are plainly proportional to increments infinitely small; we then write

$$\Delta s = \frac{4b}{3a} \Delta b, \text{ whence } \Delta b = \frac{3}{4} \frac{a}{b} \Delta s, \qquad [13]$$

. $\Delta b$ signifies the finite difference of $b$.

This formula gives the increment of the versed sine $\Delta b$ corresponding with an increase of length $\Delta s$ of the chain. We thus find that for a bridge of 100 mètres span, in which case $a$ is equal 50 mètres, and having a versed sine of 5 mètres, the latter is augmented by $0^{m}\cdot 135$ when the temperature is raised from 0 to 30°.

The section of the rods is easily calculated according to the weight they have to carry. Take the value of the weight of the roadway which the rod has to support, and add to it, according to the regulations laid down, a load of 200 kilos. a square mètre; divide the sum by 12 kilos. in the case of iron bars, and by 18 kilos. in the case of wire rope. The quotient expresses in square millimètres the section of the rod.

The section of the chain is determined according to the maximum tension which it has to support. This tension is obtained by taking into account at first only the weight of the roadway, of its load, and of the weight of the rods. We thus obtain for the section of the chain an approximative value, whence we deduce the approximative value of the chain itself. Recommencing the calculation by introducing into the total weight that of the chain, we obtain a near value for the section, which is in general sufficiently near for all purposes. The small beams supported by the rods by means of iron straps may be considered as prisms placed upon two supports and loaded with the weight of the flooring-planks, which form two semi-interspaces, having the regulation load or weight uniformly spread over the length of the beam. The dimensions of the flooring are calculated in a similar manner. The regulation load of 200 kilos. a square mètre represents the weight of three men. If the bridge is intended for the passage of vehicles, it is necessary, in the calculation of the section of the chain and that of the rods, to take into account the weight of two conveyances at least; and to consider them as crossing one another upon a given interspace. It is also necessary to consider this circumstance in the calculation for the smaller beams and the floor, independently of a weight uniformly distributed; we have then to consider a weight applied at a given point, for example in the middle, which is the most unfavourable case.

We require to calculate the lengths of the rods. If they are not equidistant, each of these lengths must be calculated by means of the equation of the parabola, and taking the sum. But the calculation is simplified when the rods are equidistant. Let us consider first the case in which there is no horizontal side. We have seen that the equation of the parabola in relation to its vertex is then $y = b \frac{x^2}{a^2}$.

Let us designate by $\lambda$ the width of an interspace; the successive lengths of the rods, computed from the axis of $x$, that is to say, from the horizontal which starts from the lowest point, will have for their respective values $\frac{b\lambda^2}{a^2}, \frac{b\,4\lambda^2}{a^2}, \frac{b\,9\lambda^2}{a^2}, \ldots \frac{bn^2\lambda^2}{a^2}$, calling $n$ the number of rods. The sum $\Sigma$ of these rods will then be $\Sigma = \frac{b\lambda^2}{a^2}(1 + 4 + 9 + \ldots + n^2)$. Now the sum of the squares of the consecutive numbers from 1 to $n$ has for its value $\frac{n(n+1)(2n+1)}{6}$, we shall then have $\Sigma = \frac{b\lambda^2}{a^2} \frac{n(n+1)(2n+1)}{6}$.

We may simplify still more this expression by observing that we have

$$a = (n + 1)\lambda, \text{ whence } \frac{\lambda}{a} = \frac{1}{n+1}.$$

Substituting this value for $\frac{\lambda}{a}$, and reducing, we find

$$\Sigma = b \frac{n(2n+1)}{6(n+1)}, \text{ or } \Sigma = \frac{1}{3} bn \frac{2n+1}{2n+3}. \qquad [14]$$

If there is a horizontal side, the most simple method is still to take the parabola in relation to its vertex, in which case the equation [8] is reduced further to the form $y = \frac{p}{2Q} x^2 = b \frac{x^2}{a^2}$, since the transposition of the axis of $x$ does not change the parameter. But the abscissa of the points

of attachment of the rods are then, designating by $\epsilon$, the half-interspace, $\epsilon$, $3\epsilon$, $5\epsilon$, $7\epsilon$, .... $(2n-1)\epsilon$, $n$ designating the number of the rods. We have then in this case

$$\Sigma = \frac{b\,\epsilon^2}{a^2}\,[1 + 9 + 25 + 49 \ldots + (2n-1)^2].$$

Now the sum of the squares of the $n$ first unequal numbers has for its value $\frac{(2n-1)\,2n\,(2n+1)}{6}$,

we then get $\Sigma = \frac{b\,\epsilon^2}{a^2}\,\frac{(2n-1)\,2n\,(2n+1)}{6}$.

This expression may be simplified by observing that we have $a = \epsilon\,2n+1$, whence $\frac{\epsilon}{a} = \frac{1}{2n+1}$.

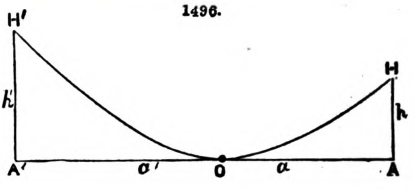
Substituting and reducing, we obtain as a final result

$$\Sigma = b\,\frac{(2n-1)\,2n}{6\,(2n+1)} = \frac{1}{3}\,b\,n\,\frac{2n-1}{2n+1} \qquad [15]$$

We may remark that the values of $\Sigma$ given by the formulæ [14] and [15] differ very slightly from $\frac{1}{3}\,b\,n$; so that when we only require a summary estimate, we can get the sum of the lengths of the rods by multiplying the third of the greatest by the number of these rods.

The formulæ [14] and [15] give the sum of the lengths of the rods only as far as the tangent to the vertex of the parabola circumscribed on the chain. It is necessary to add further the lengths of the portions of the rods comprised between the tangent and the roadway. If the latter is horizontal, calling $\delta$ the distance from the vertex of the curve to the roadway, we must add $n\,\delta$ to the sum already calculated. Sometimes the roadway has a slightly parabolic form, the convexity being turned upwards. In this case it would be necessary further to add to the sum of which we speak the sum of the ordinates of the new parabola, corresponding with the same abscissæ, they are calculated like the first sum.

1496.




We have supposed up to the present that the chain was composed of two symmetrical portions, its vertex corresponding with the middle of the roadway. This is not always the case; but knowing the heights $h$ and $h'$, Fig. 1496, of the supposed points of attachment H and H' above the tangent to the vertex, and the length A A' = L of the roadway, it is easy to determine the distances $a$ and $a'$ from the summit of the parabola to the extremities of this roadway. For we have, first, $a + a' = L$.

Next we have, since the points H and H' are upon the parabola, $h = \frac{p}{2Q}\,a^2$ and $h' = \frac{p}{2Q}\,a'^2$,

whence $\frac{h}{h'} = \frac{a^2}{a'^2}$, or $\frac{a}{a'} = \frac{\sqrt{h}}{\sqrt{h'}}$

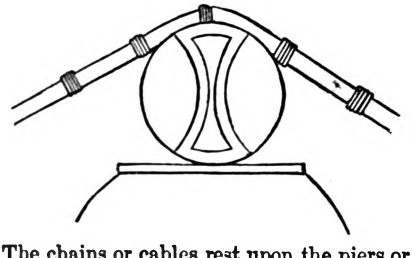
We also obtain from the two relations between $a$ and $a'$ the values

$$a = L\,\frac{\sqrt{h}}{\sqrt{h} + \sqrt{h'}}, \text{ and } a' = L\,\frac{\sqrt{h'}}{\sqrt{h} + \sqrt{h'}},$$

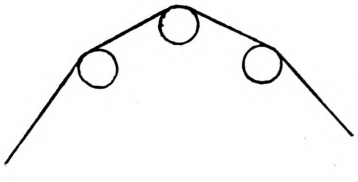
which determine the position of the point O. This point being known, we may apply to each of the branches O A and O A' the calculations and the formulæ belonging to the case in which the point O was supposed to be in the middle of the roadway.

We have also supposed that there was only one chain on each side of the bridge; generally there are several; but the projection of their vertices upon a vertical plane parallel to the direction of the bridge is upon the same parabola. The calculations are made as if all these vertices belonged to one chain. If there are four, the first bears the rods 1, 5, 9, &c.; the second, the rods 2, 6, 10, &c.; the hird, the rods 3, 7, 11, &c.; the fourth, the rods 4, 8, 12, &c.

1497.



1498.

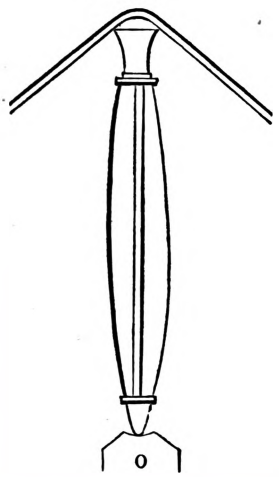


The chains or cables rest upon the piers or abutments by means of fixed or movable supports. In the first case, these supports are piers of masonry, or cast-iron pillars. The chains are not attached to these; they pass over rollers, or portions of rollers, known as revolving sectors, Fig. 1497, which themselves rest upon a plane surface. The intention of this arrangement is to distribute the pressure more equally over the different portions of any one chain, and to counteract the rupture which might result from an inequality of tension between two consecutive portions of the chain. Occasionally the chain is even made to pass over three rollers, of which one, that in the middle, is placed higher than the others, in order to diminish the angle of flexion of the chain, Fig. 1498.

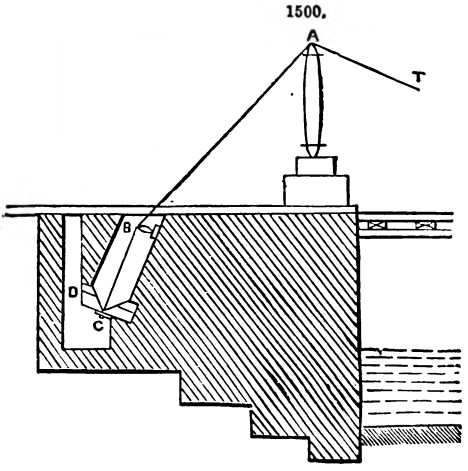
The movable supports are columns or large cast-iron uprights, resting upon a fixed support by means of a horizontal rounded edge. This arrangement has the same intention as the use of friction-rollers or revolving sectors. The tension is distributed equally between the two divisions of the cable, and the resultant of the two equal tensions is directed according to the bisectrix of the angle formed by the two divisions; it leans towards one or the other side, according to the inequality of the load of the two roadways. It is plain that if, from the effect of a passing load upon one of these two roadways, the tension of the chain is augmented, the chain is drawn towards that side, and by adherence draws with it the movable pillar, making it revolve round its resting point O, Fig. 1499, until the tension diminishing on that side and increasing on the other, becomes equal to the two divisions.

The base of the pier must be so arranged that, meeting the result of the two tensions, with the weight of the pier and the revolving column, we obtain a total resultant which meets the base of the pier at a point in its interior, sufficiently removed from the nearest edge to avoid crushing the stone, and will also make with the vertical an angle inferior to the angle of the friction of the pillar on the stone, that is to say, inferior to 37°, or the *angle of friction*.

1499.



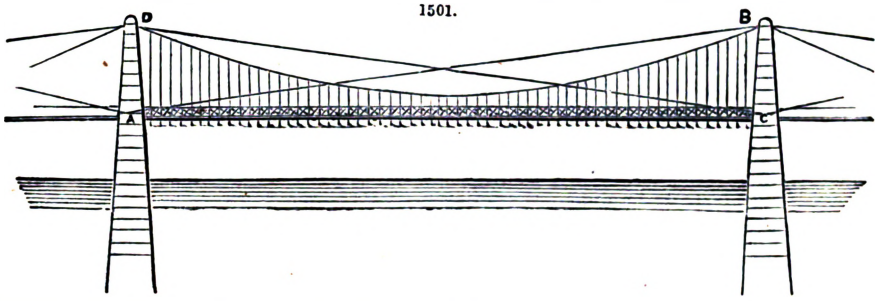

1500.




Each of the extremities of the chain, after having passed over the fixed or movable support which corresponds to the abutment, is carried into the ground, penetrating into a solid mass of masonry, united to the pier. Fig. 1500 shows this arrangement; the chain after passing over the support, takes the direction A B, generally more nearly approaching the vertical than the last side T A; at B it assumes a bent direction, so as not to require in the mass where it is moored dimensions needlessly great; with the point of inflection there usually corresponds a smaller revolving support; the chain afterwards descends in the direction B C into an inclined channel, which is terminated by a narrow opening closed by a plate of cast iron, to which the chain is fixed; below this is the mooring-hole C, into which there is access by the opening D to reach the point of attachment. The same opening usually serves for access to the two cavities on the same bank communicating one with another by a vaulted gallery. It is necessary for the equilibrium and stability of the system, that on composing the tension in the direction of A B with the weight of the mooring-block, a resultant should be obtained which meets the mass of the block at a point in its interior, at a sufficient distance from the nearest ridge, and which will make, with the vertical, an angle inferior to the *angle of friction* considered above. In accordance with this, the dimensions and consequently the weight of the block are determined.

As a rule, no great height is given to the supports, whether fixed or movable; it follows that the tension Q is rather considerable, for it varies in inverse ratio with the height; but in an economical point of view there is less inconvenience in slightly augmenting the section of the chains, than in increasing the height of the supports, which would besides have the effect of

1501.



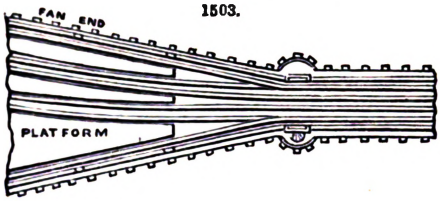

diminishing stability. Where we are obliged to give a great height to the supports, they are united by stays A B, C D, Fig. 1501, which are attached to the top of one of the piers and fixed at the foot of the other: the figure shows this arrangement

We have said that the actual point of attachment of the chains does not coincide with that which we have called the imaginary point of attachment, which is upon the vertical of the extremity of the roadway. In this interval, the chain having only its own weight to carry, affects the form of an arch of chainwork, which accords with the parabola circumscribed on the chain; but the two curves differ then so little one from the other, that we may without appreciable error consider the arch of chainwork as the prolongation of the parabola.

*Iron Bridge Building.*—The Charing Cross Bridge, erected to support the Charing Cross Railway over the Thames, occupies the site of the Hungerford Suspension Bridge.

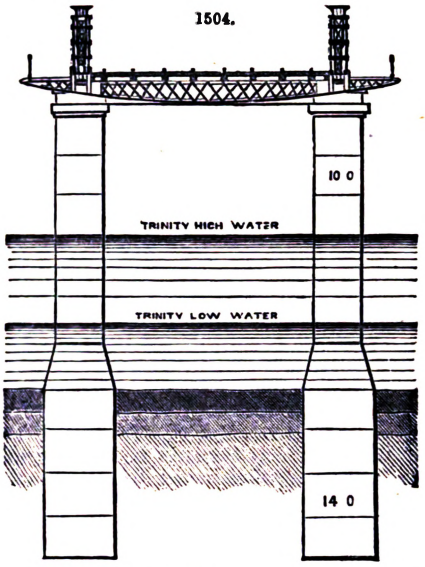
This bridge comprises nine spans, Fig. 1502, six of 154 ft. and three of 100 ft. The superstructure over the three latter spans is fan-shaped, Fig. 1503, inasmuch as the ground available for the Charing Cross Station being somewhat restricted in length, it was necessary to begin the widening out on the bridge. It was found necessary to divide the opening between the Middlesex pier and abutment into three spans of 100 ft., instead of into two spans of 154 ft., as on the Surrey side.

1503.




The bridge is carried by cylinders, sunk into the bed of the river, and by the piers of the Hungerford Suspension Bridge, Fig. 1502, the upper portions of which have been removed, while the lower portions have been added to and modified, so as to adapt them for the railway bridge. The abutments of the Hungerford Suspension Bridge are also retained, but have been considerably lengthened and altered. The width of the river at the bridge is 1350 ft. The greatest depth of water between the two brick piers is 13 ft. below low-water spring tides, and the average depth is about 10 ft. The rise of spring tides is 17½ ft. The level of the rails is 31 ft. above Trinity high-water mark, and the clear minimum headway is 25 ft. above the same level.

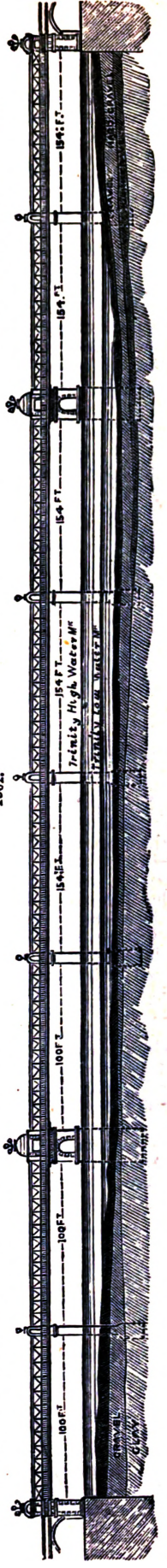
1504.



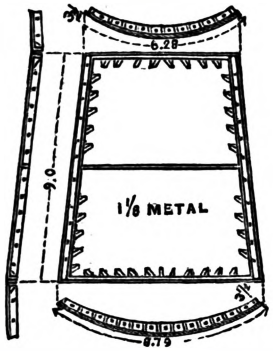

This bridge was designed by Hawkshaw, but the practical part of the work, which is by far the most considerable portion, is due to the engineering skill of Joseph Phillips.

*Cylinders for the Openings* 154 *ft. Span.*—The cylinders, excepting those at the fan end, are 14 ft. diameter below, and 10 ft. diameter above the ground, the junction between the two sizes being effected by an intermediate conical length, Fig. 1504. There are four piers (three intervening between the towers of the Hungerford Suspension Bridge and one between the tower and the abutment on the Surrey side) formed of cylinders of the above diameters, and each of the piers consists of two cylinders, 49 ft. 4 in. apart, from centre to centre. They are of cast iron, and are shown in detail in Figs. 1505 to 1507. The circumference of each cylinder of 14 ft. diameter, is divided into seven equal parts or segments, the segments being generally 9 ft. high; that of the cylinders 10 ft. diameter, is divided into five equal parts or segments, each segment being also generally 9 ft. high; whilst that of the intermediate or conical piece is similarly divided into five equal parts or segments, each 9 ft. high. The segments are fastened together inside, by bolts 1¼ in. diameter, passing through flanges cast on the top, bottom, and sides of the segments. A horizontal interior strengthening rib is cast on the middle of each segment. All the joints of the segments, both horizontal and vertical, are planed, and spaces are left inside between the flanges for the introduction of iron cement, to render the joints water-tight. The vertical joints of the segments, in each of the two lengths of different diameters respectively, are over one another. There are thus continuous vertical lines of ribs, securing a strong columnar arrangement. The

1502.



1505.




1506.

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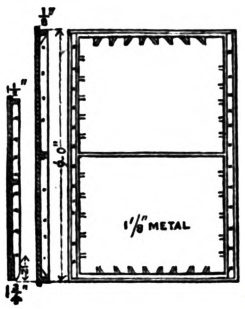
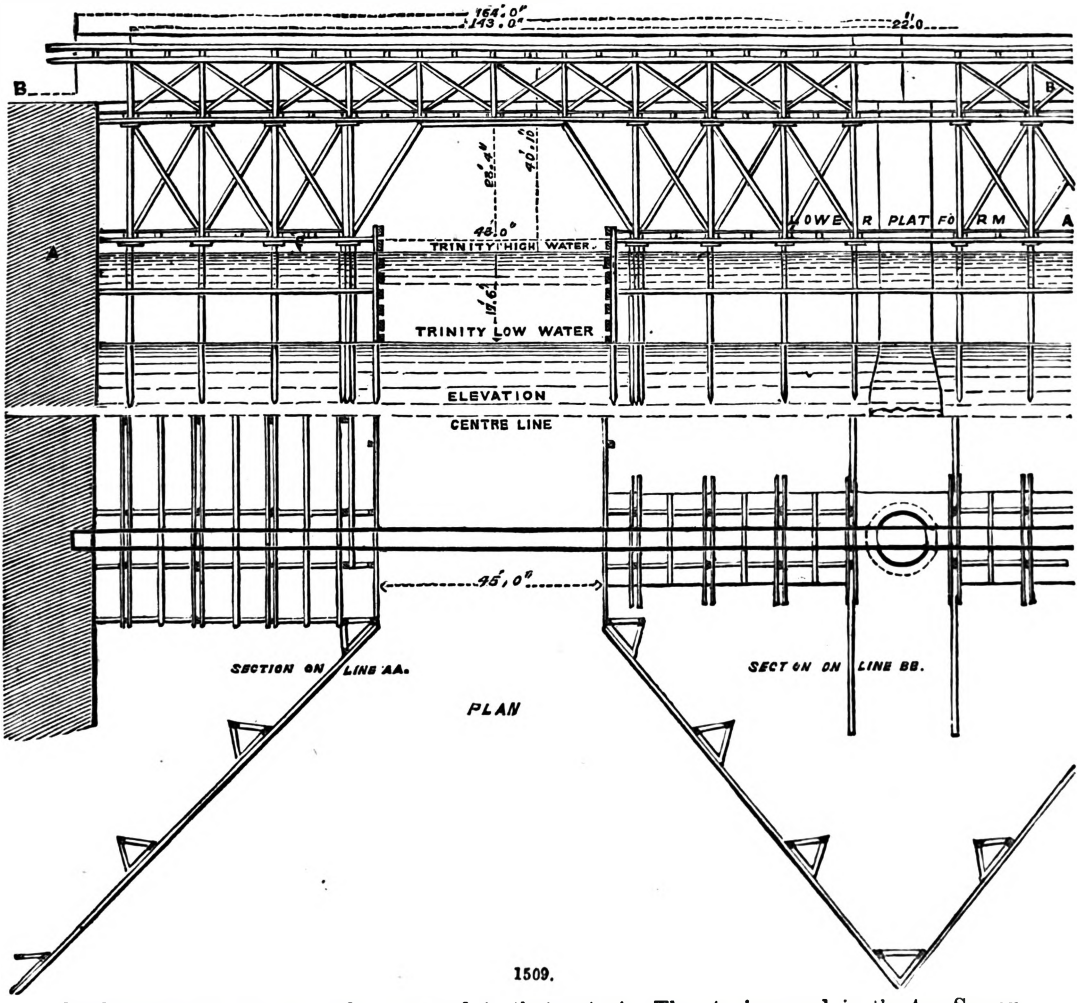



horizontal joints can also be made to fit better in this way than by breaking the vertical joints. The thickness of the metal in these cylinders is $1\frac{1}{8}$ in. throughout, excepting in the bottom length, where it is $1\frac{1}{2}$ in.

*Sinking the Cylinders.*—The staging for sinking the cylinders consisted of piles erected round the pier, supporting a stage or platform at the level of 4 ft. above high-water mark. When this staging was in its place, an opening of 45 ft. was left between two adjoining piers; but in order that the navigation might not be interrupted, only two openings, in the space between the two

1508.




1509.

brick piers, were allowed to be narrowed to that extent. The staging used in the two Surrey openings, which was generally similar to that employed for the other openings of the same span, is shown in Figs. 1508, 1509. The part up to the lower platform was erected for the purpose of sinking the cylinders. This was afterwards carried up, and the 45-ft. opening spanned, for the purpose of erecting the girders.

The strata through which the cylinders are sunk, Fig. 1502, consist of mud and gravel, of varying thicknesses, overlying the London clay. The cylinders were sunk by excavating the material from the inside, by means of divers, and then by weighting them as the excavation proceeded, until they had passed through all the porous material, and had entered a few feet into the solid London clay. The water was then pumped out, and the cylinder was kept dry during the rest of the operation. The sinking was then proceeded with, by excavating the material and by weighting the cylinders. The weight with which it was found necessary to load the cylinders, in order to overcome the friction of the sides, and to sink them to their final depth, averaged about 150 tons. The London clay extended to a depth far below the level at which the cylinders were founded.

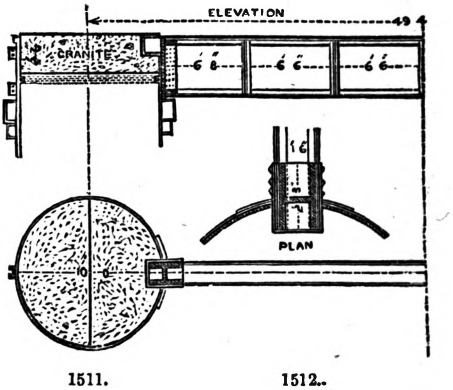
The cylinders constituting the pier between the Surrey abutment and the brick pier, are sunk to a depth of 52 ft. below Trinity high-water mark. Those between the two brick piers are sunk to a depth of 62 ft. below the same level, excepting the up-stream cylinder of the middle pier, which had to be sunk 10 ft. deeper, on account of some of the material through which it passed being softer than that met with at the sites of the other cylinders.

*Filling-in the Cylinders, and Weighting.*—After the cylinders had been sunk, and the material had been excavated, they were filled with concrete up to where the conical part commences, and with brickwork from that level to the under-side of the granite bearing-blocks occupying the top of each cylinder. The concrete was composed of Thames gravel or ballast, that obtained from the excavation from the inside of the cylinders being used, so far as it was suitable and sufficient. This was mixed with Portland cement, in the proportion of one part of cement to seven parts of gravel. The brickwork is generally composed of the best paviour bricks, set in Portland cement mortar, in the proportion of one part of cement to two parts and a half of sand.

Before the lengths above high water were put on, the cylinders, after they had been filled with the concrete and brickwork, were weighted with a load of about 450 tons, excepting the two cylinders in the pier nearest to the Surrey side, which were the first sunk, and weighted each with 700 tons, that being about the greatest load that could come upon any one cylinder, assuming the four lines of rails on the bridge to be loaded with locomotive engines. Upon the removal of the loads, it was found that each of the cylinders which had been weighted with 700 tons had permanently sunk 4 in., and each of the others that were loaded with 450 tons had permanently sunk, on an average, nearly 3 in. The larger loads were applied in order to test the strength of the foundations, and the subsequent smaller loads to bring the cylinders to a bearing, so as to prevent any settlement, after the completion of the bridge, from the weight of the permanent and moving loads. The load was applied by piling the permanent rails of the railway on the cylinders. After it was removed, the top lengths were put on, and were filled in with brickwork, and then the granite bearing-blocks were fixed in place. These blocks are 2 ft. 6 in. thick, and are in two equal pieces, which, when together, fill the cylinder, the joint being under and longitudinal with the girders. The granite blocks project 1 in. above the top of the cylinders, in order that the weight may be prevented from coming on the upper edge of the ironwork.

Each pair of cylinders forming a pier is connected together transversely by a wrought-iron box-girder, 4 ft. deep, strongly attached to the top of each, Figs. 1510 to 1512. This girder also serves the purpose of a cross-girder for supporting the road-way. Assuming the four lines of way on the bridge to be loaded with locomotive engines, the pressure on the base of the cylinders would amount to about 8 tons the square ft., and that on the brick-work at the top of the cone, where the cylinder is 10 ft. diameter, to about 9 tons the square ft. The former pressure, however, is on the supposition that no relief is afforded by the friction of the sides against the material through which the cylinders penetrate. If this were taken into account, as it should be, the 8 tons the square ft. would be much reduced, and it is clear that this pressure will not be approached.

1510.




1511. 1512.

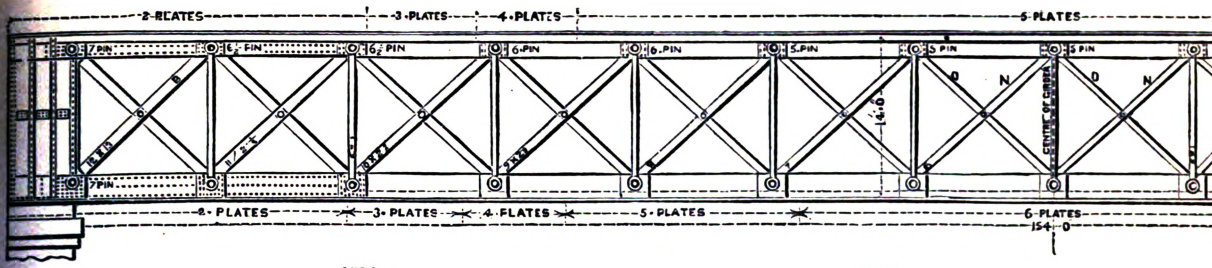
*Superstructure of the Openings* 154 *ft. Span.*—The superstructure of each of the openings, 154 ft. span, consists of two main girders, underneath which are cross-girders, Fig. 1504. The main girders are, like the cylinders, 49 ft. 4 in. apart from centre to centre transversely, leaving a space between them sufficient for four lines of rails, the roadway platform being supported by the cross-girders. For the purpose of carrying the footpaths, each of which is 7 ft. wide, the cross-girders extend beyond the main girders, forming a series of cantilevers on each side of the bridge.

*Main Girders Spanning the* 154-*ft. Openings.*—These girders are of wrought iron. They are not continuous over two or more openings, but are all detached. Each has to support, inclusive of its own weight, a maximum distributed load of about 700 tons. The elevation, sections, and details of these girders are shown in Figs. 1513 to 1530. The extreme depth of the girders is 14 ft., and the depth between the centres of gravity of the top and bottom members is 12 ft. 9 in. When the girders are loaded with a maximum strain of 4 tons the sq. in. in compression, and of 5 tons the sq. in. in extension (which are the limits allowed for the wrought-iron work throughout the bridge), the sectional area in the top, at the centre of the girder, will be somewhat less than 300 sq. in., and that in the bottom, excluding the rivet-holes, will be somewhat less than 235 sq. in.; these being the respective central areas of the girders.

The sides of the girders between the bearings are divided by vertical bars into fourteen equal

parts, each division containing a double set of two diagonals crossing each other. These are placed, as nearly as practicable, at an angle of 45° with the top and bottom of the girder; and both the diagonals and the vertical bars are connected to the top and bottom webs by pins of puddled

1513.

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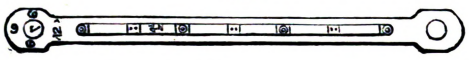

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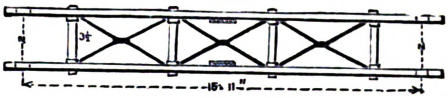

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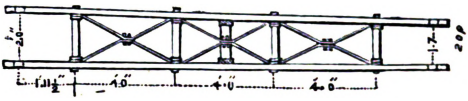

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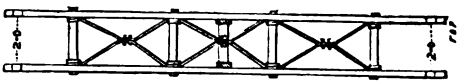

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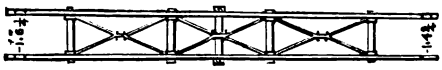

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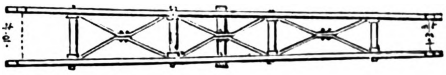

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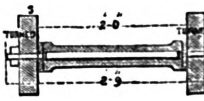

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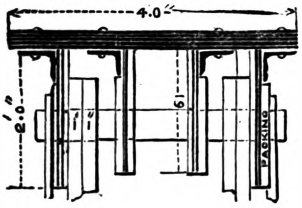


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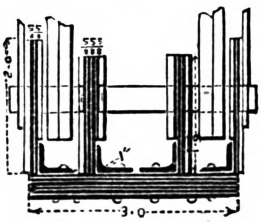


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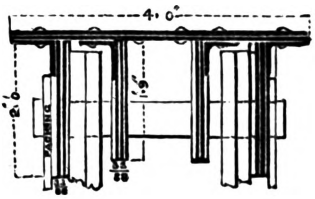


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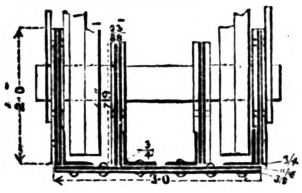


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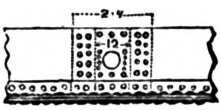
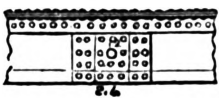



1530.



steel. The top and bottom webs of the girders are of boiler-plate, and consist of horizontal tables 4 ft. wide at the top and 3 ft. wide at the bottom, and of four vertical ribs, the two outer rows being 24 in. deep, and the two inner 21 in. deep. The joints of the plates, in the horizontal tables

of the top and bottom webs, are covered by a continuous plate running the whole length of the girder: that in the top being of the same thickness as the plates covered, and that in the bottom $\frac{1}{16}$ in. thicker, Figs. 1525 to 1528. The joints in the vertical ribs in the top and bottom occur near the pin-holes, and are covered by 1-in. plates, 2 ft. 4 in. long, placed on both sides of the ribs, thus forming a good bearing for the pins, Figs. 1529, 1530. The vertical ribs are united to the horizontal tables by angle-iron, 6 in. by 6 in., by 1 in. thick in the centre and $\frac{3}{4}$ in. thick at the ends, covered at the joints. The rivets used throughout the top and bottom of the girders are 1 in. diameter, and their pitch is about 4 in.

The aggregate thickness of the plates in the horizontal table of the top in the centre of the girder being $3\frac{1}{4}$ in., and in the bottom $3\frac{3}{16}$ in., without the angle-iron, and $4\frac{1}{8}$ in. and $4\frac{3}{16}$ in. respectively, with the angle-iron, but excluding the angle-iron covers, it would not be easy to unite the parts composing such a thickness by rivets passing through holes punched in the metal. However perfectly the holes may be set out in the first instance, the process of punching always stretches the iron; so that, when the plates are put together, the holes do not come accurately over one another. Neither would they have been truly cylindrical throughout, as they are always, when punched, larger on one side than the other; so that where so many thicknesses had to be united, imperfect riveting would have resulted, unless rimering out to a great extent had been resorted to.

The diagonals which act as ties are of Howard's rolled suspension links, each separate tie being composed of two or three links riveted together. The diagonals acting as struts are each in one solid forging. The struts and the ties have swelled ends for the pins. The struts are united together in pairs, by zigzag bracing of wrought iron, $4\frac{1}{2}$ in. wide by $\frac{3}{4}$ in. thick, riveted to them, and by bolts passing through cast-iron distance-pipes. The ties, also in pairs, are not united together; but in the centre of the girders, where the diagonals act both as struts and ties, the pairs are united together in the two central spaces by the zigzag work. The dimensions of the struts vary from 12 in. by 3 in. at the ends, to 6 in. by $2\frac{1}{2}$ in. in the middle; and of the ties, from 12 in. by $2\frac{1}{2}$ in. at the ends, to 6 in. by 2 in. in the middle. They are 7 in. diameter at the ends of the girders, decreasing to 5 in. diameter at the centre, and are 11 ft. apart from centre to centre.

At the ends of the girders the sides over the supports are boxed, being composed of $\frac{3}{8}$-in. plate iron, stiffened by angle and T iron. Where the girders bear upon the brick piers and upon the Surrey abutment, they rest upon roller bed-plates; but upon the cylinders sheet lead only is interposed between the girders and the granite blocks. The force of expansion and contraction will probably cause the cylinders between the brick piers to rock to and fro to a certain but inappreciable extent. The girders were put together in place on the staging, Figs. 1508, 1509. The top of the girder was put together on the top upper platform, and the bottom of the girder on the top lower platform, the two platforms being kept at the correct distances apart by diagonals, converting the whole into a framework of timber. The supports on the platforms, on which the girders were erected, were accurately adjusted to the proper camber of the girders.

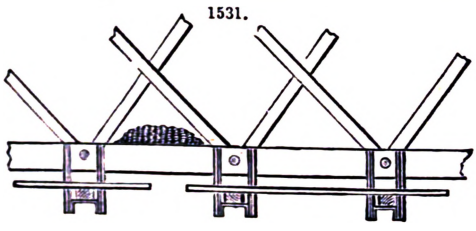
The struts, with the diagonal bracing, were also put together at the works of Cochrane and Co., and the pin-holes were bored out to the full size; so that they, and also the ties, were sent up in a complete state. When the top and bottom webs were in place, the struts and the ties were erected, and the pin-holes in the girders were accurately bored out, by means of a boring apparatus worked by a small steam-engine, the gauge of the running wheels of which was so adjusted, that it might work backwards and forwards on the two outer vertical ribs of the lower part of the girder. Great care was taken to ensure accuracy in the direction and position of the holes. The pins, after being coated with grease, were forced into the holes, the diameter of the latter being such that the former could only be driven in by exerting a considerable force, a perfect fit being thereby established. The vertical bars dividing the sides into the several spaces are 6 in wide by 1 in. thick. They have not been taken into account in calculating the strains. They fit on to the ends of the steel pins, and are in pairs, one on either side, and outside the outer vertical ribs of the top and bottom, and are connected together by bolts and distance-pipes. The only use they serve is to stiffen the girder.

The ends of the pins are covered with circular castings, screwed on; and over the ends, resting on the cylinders, ornamental castings are fixed

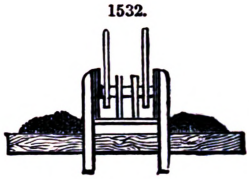
The weight of each main girder spanning the 154-ft openings is 190 tons.

One of the main girders was tested, when in place, with a distributed load of 400 tons, and the deflections were accurately taken. The load being very great, and the girder being unconnected transversely (the cross-girders not having been fixed), great care had to be observed in putting on the weight, which consisted of the rails of the railway. The manner in which it was loaded will be understood from Figs. 1531 1532 The greatest deflection in the centre, when the

1531.



1532.

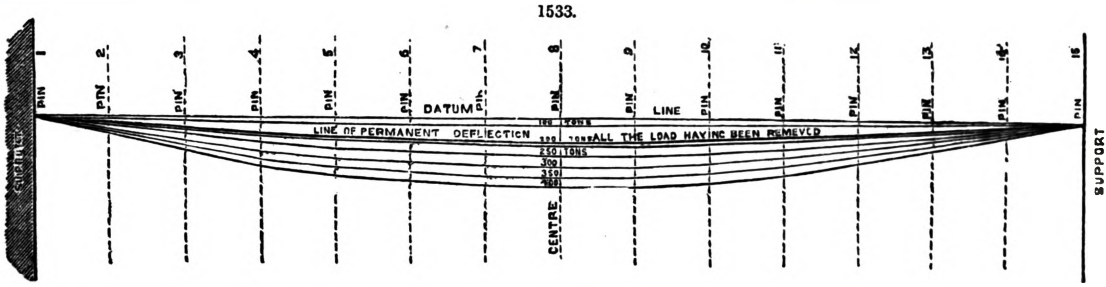


load was on, was $1\frac{5}{16}$ in., and the permanent deflection, after the load was removed, was $\frac{1}{2}$ in., Fig. 1533. If the girders had been rigidly connected transversely by the cross-girders, the deflection would doubtless have been less. This has since been proved to be the case. The whole of

the bridge, in its completed state, has been tested by a maximum load, and the greatest deflection of the main girders has not been more than $\frac{3}{4}$ of an in. in the centre.

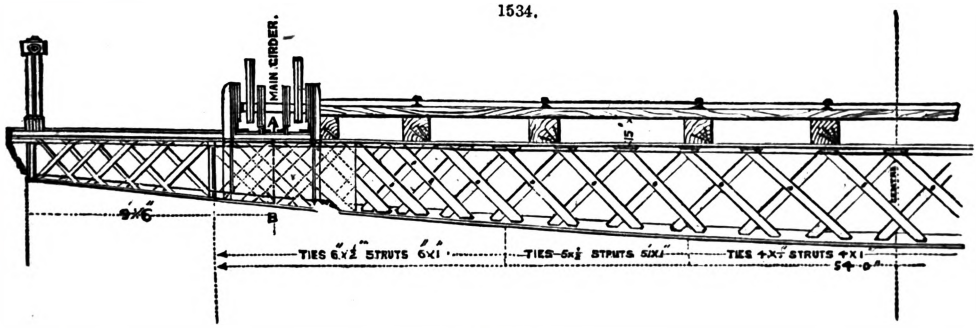
The plate iron used throughout the bridge was also tested. These are interesting, as both the extension and the permanent set were carefully taken by an accurate *extensometer*.

1533.

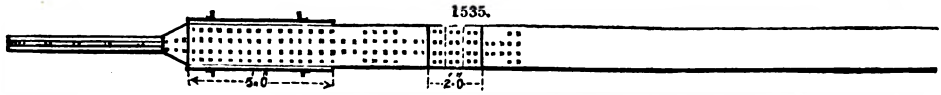



It has been before stated that the girders are all detached, and not continuous over two or more openings. Hawkshaw's original intention was to connect the girders spanning the two end openings on the Surrey side, and also to connect the girders spanning the four central openings. As regards the girders spanning the two openings on the Surrey side, it was found that it was not easy to gain the full advantage from continuity, inasmuch as the girders having to support a considerable load, the thickness of the plates in the top and bottom was too great to render it practicable to reduce them to a minimum at the point of contrary flexure. Moreover, the strain on the diagonals would have been greater at the central support than at the end supports, and the uniformity in size of the struts and ties could not have been maintained, had their correct dimensions consequent upon continuity been adopted. It was also desirable not to increase the strain on the diagonals, as the end struts are already large forgings. The same remarks apply, more or less, to the girders spanning the four central openings, although in this case greater advantage would have been gained by continuity. More difficulty, however, would have been experienced in their erection, inasmuch as the Conservators of the River Thames only allowed the staging to be erected in the river for two of the central openings at one time. It is clear, also, that much more trouble would have been incurred in constructing continuous girders over several openings, than in putting together a series of detached girders. In the former case there would be a multitude of dissimilar parts, whilst in the latter all the girders would be duplicates of one

1534.

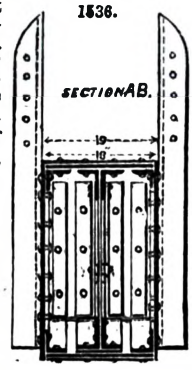



1535.

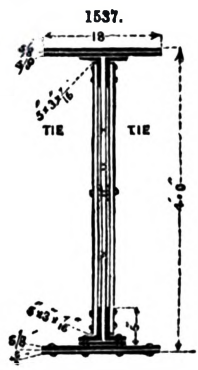



another. Better workmanship is thus ensured, and at a less cost a ton. In order to ascertain whether any saving of metal would be effected by the girders being constructed on the continuous or non-continuous system, drawings of both were prepared, and the weights were accurately calculated. The difference was inconsiderable in the case of the side openings, and was not of sufficient importance over the central openings to counterbalance the advantages to be derived from non-continuity.

1536.




1537.



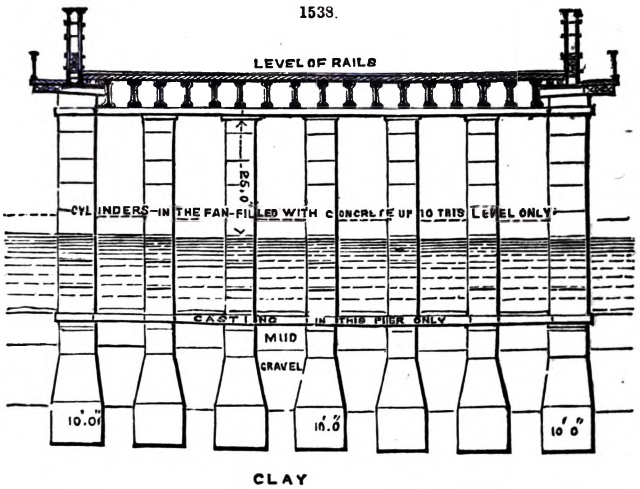

*Cross-girders for the Openings* 154 *ft. Span.*—The cross-girders for the openings, 154 ft. span, are shown in Figs. 1534 to 1537. They are of wrought iron, and are suspended from the main girders. The top and the bottom of that portion of the cross-girders between the main girders consist of two plates, 18 in. wide by $\frac{5}{8}$ in. thick. The sides are of lattice-bars, united to the top and bottom by two angle-irons, 5 in. by 3 in. by $\frac{7}{16}$ in. thick. These cross-girders are 4 ft. deep in the middle and 2 ft. $1\frac{1}{8}$ in. deep where the cantilevers are united to them outside the main girders,

the bottom being fish-bellied, and the top having a camber of 3½ in. in the centre. The lattice-bars are fixed at an angle of about 45° with the top and bottom. The ties are in two bars throughout, and each bar varies from 6 in. by ½ in. at the ends to 4 in. by ½ in. in the middle. The struts are in one bar passing between the two ties, and vary from 6 in. by 1 in. at the ends to 4 in. by 1 in. in the middle. The rivets in the cross-girders are ⅞ in. diameter. The cantilevers decrease from 2 ft. 1½ in. deep at their junction with the cross-girders to 1 ft. 2 in. deep at the extremities. The top and bottom of the cantilevers are composed of two angle-irons, 3½ in. by 3 in. by ½ in. thick, and the sides are of lattice-bars also placed at an angle of about 45° with the top and bottom; the ties likewise consist of two bars and the struts of one bar passing between them, each of the former being 2 in. by ¾ in. and the latter 2 in. by ¾ in.

It will be seen, therefore, that the cross-girders are generally similar in character to the main girders. They are suspended from the under-side of the main girders at the points where the pins occur. They are therefore placed 11 ft. apart, from centre to centre. The sides of the cross-girders, where they are underneath the main girders, are boxed in with plate iron. They are suspended by four angle-irons—two on either side—and outside the outer vertical ribs of the bottom of each main girder, to which, and to the boxed sides of the cross-girder these angle-irons are riveted. By this means a strong and good attachment is established. The cross-girders are connected together by wrought-iron cross-bracing attached to the centre of each, Fig. 1503. Each cross-girder, including the two cantilevers, weighs 9 tons. They were tested by erecting two cross-girders in the contractor's yard, placed transversely 6 ft. apart in the clear, the cantilevers being removed. They were then loaded with 140 tons (equivalent to 70 tons on each girder) distributed over the span. The maximum deflection in the centre, when the load was on, was 1 in.; and the permanent deflection, when the load was removed, was ¼ in. This result would doubtless have been better had the cross-girders been in place and rigidly fixed at the ends to the main girders. The whole of the cross-girders have since been tested in place with a maximum load, and the deflection has in no case been more than ⅜ in. in the centre.

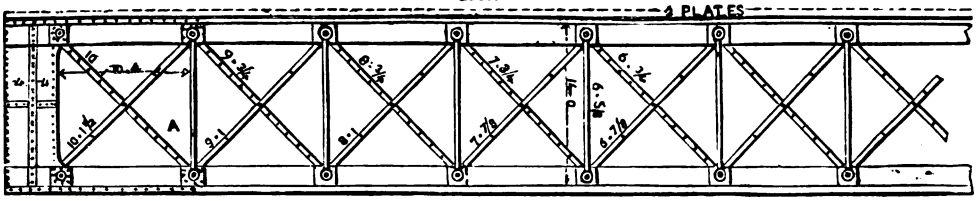
*Fan End.*—The superstructure of the three openings, 100 ft. span each, of the fan end is supported by the Middlesex brick pier and by the Middlesex abutment of the bridge, and intermediate to these by piers of cast-iron cylinders, that next to the brick pier consisting of a row of seven cylinders, and that next to the abutment of a row of nine cylinders. In these two rows, Figs. 1503, 1538, the outer cylinders are 10 ft. diameter below and 8 ft. diameter above the ground, and the inner ones are also 10 ft. diameter below but only 6 ft. diameter above the ground, the junction between the two lengths of different diameters being effected by a conical length. The circumference of the lower lengths of the cylinders, 10 ft. diameter, is divided into segments, which are generally similar, and are connected together in the same way, as the upper lengths of the cylinders already described, of the same diameter, in the piers of the openings 154 ft. span. The upper lengths of the outer cylinders 8 ft. diameter, and of the inner cylinders 6 ft. diameter, are not divided into segments, but are cast in pieces complete on the circumference, and 5 ft. long. These pieces are fastened together, by bolts 1¼ in. diameter passing through flanges cast on the top and bottom. All the joints throughout these cylinders are made water-tight by iron cement. The cylinders in these two piers have been sunk in place, precisely in the same manner as the cylinders of the openings of 154 ft. span, and to depths averaging about 40 ft. below Trinity high-water mark. When in place and when all the material had been excavated from the inside, they were filled with Portland cement concrete to the level of about 5 ft. above Trinity high-water mark. It was not considered necessary to fill in the remaining portion of these cylinders.

As some irregularities, or deviations from the perpendicular, occurred in sinking some of the cylinders in the row next the Middlesex brick pier, a horizontal casting, extending over all the cylinders of this row, was bolted to them at about the level of th ground, Fig. 1538; on this casting the upper parts of the cylinders of this pier are fixed.

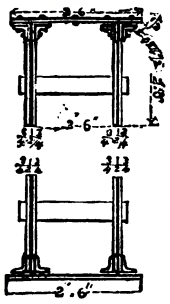



On account of the great width of fan, which increases from 49 ft. 4 in. from centre to centre of the outside girders at its commencement at the Middlesex brick pier (this being the width between the parallel main girders spanning the 154-ft. openings) to 168 ft. from centre to centre of the outside girders at the abutment, the system pursued in the other openings, of supporting the roadway on cross-girders suspended from outside main girders, was clearly inadmissible. It was also undesirable to introduce intermediate main girders, projecting above the roadway. The roadway over the fan is, therefore, carried by interior plate-girders, laid at right angles to the piers and the abutment, and by the outside main girders, which are at the angle of inclination of the fan. These latter, Figs. 1539 to 1542, are of the same depth, and although lighter in all the parts, are generally of the same character, and are fixed at the same level, as the girders

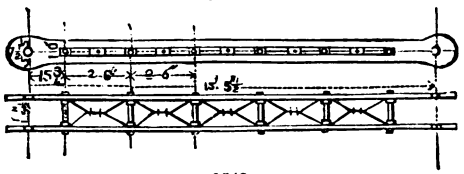
1539.



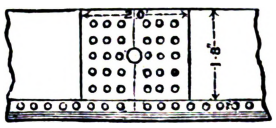

1540.



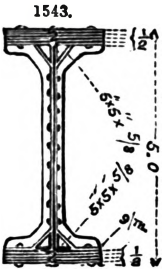
1541.



1542.



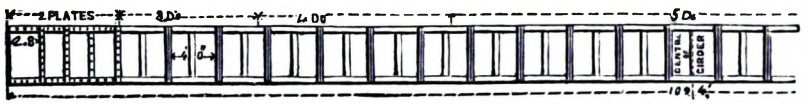
1543.



of the openings 154 ft. span. The faces of the bridge have, therefore, a uniform appearance throughout.

The interior plate-girders, where they bear on the cylinders, rest on a bed-plate, Figs. 1503 to 1543, extending over all the cylinders of each row. They are connected together by cross-bracing in the centre of each span, and at points intermediate between the centre and the supports: and where they rest on the Middlesex pier and abutment are built into the brickwork. The bottom of these girders is at a lower level than the bottom of the outside main girders, inasmuch as it was impossible to obtain sufficient depth without resorting to this arrangement. As it is, the depth of these girders is only 5 ft., or $\frac{1}{20}$ of the span. If the spans in the fan had been 154 ft., the interior plate-girders instead of being $\frac{1}{20}$ would have been less than $\frac{1}{30}$ of the span. Hence the advantage of introducing the smaller spans of 100 ft. The elevations and sections of the interior plate-girders are shown in Figs. 1543, 1544. They are of the ordinary construction, and weigh about 26 tons each.

1544.




The outside main girders do not make exactly the same angle with the centre line produced of the parallel portion of the bridge. The shape of the fan is therefore not accurately that of an isosceles triangle—the distance between the centre line of the fan and the centre line produced of the parallel portion of the bridge, being 7 ft. 9 in. at the Middlesex abutment, Fig. 1503. These outside main girders, which are over the centre of the outside cylinders of the piers, are raised above the interior plate-girders by cylindrical making-up pieces of the same diameter (8 ft.) as the upper lengths of the outside cylinders, Fig. 1538. These cylindrical pieces are filled with brick-work in cement, resting on the bed-plate, the top being covered with a bed of an inch in thickness of Portland cement, raised $\frac{1}{2}$ an in. above the top of the cylinder, and forming the bearing surface of the girders.

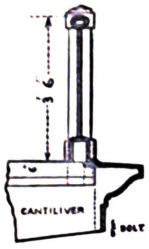
The triangular spaces between the outside main girders and the outer interior plate-girders are filled in with cross-girders, riveted to the sides of the latter and suspended underneath the former, and are terminated by cantilevers projecting beyond the face-girders, Figs. 1503, 1538. These cantilevers are similar to those outside the main girders of the 154-ft. openings, and like them are placed about 11 ft. apart from centre to centre, thus preserving the uniformity.

The girders of the fan rest directly on their supports, no rollers being interposed, excepting underneath the outside main girders, where they rest on the Middlesex brick pier and abutment; but the bearings for the interior plate-girders on the cast-iron bed-plate over the cylinders are planed. The ends of the cylinders on which the bed-plate rests are also planed.

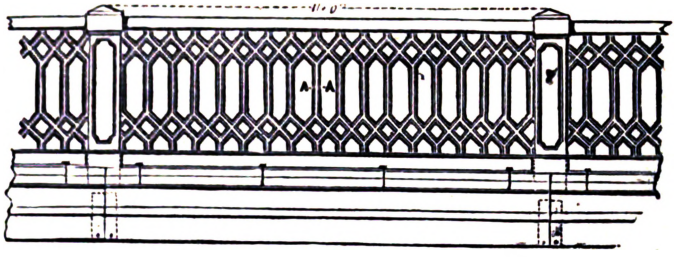
*Roadway and Footpath Platforms.*—The roadway platform over the openings 154 ft. span, consists of planking 4 in. thick, spiked to longitudinal timbers, 15 in. by 15 in., placed underneath the rails, and bolted to the cross-girders. The roadway platform over the fan end consists of planking 6 in. thick, secured to the interior plate-girders and to longitudinal timbers spanning the cross-girders in the triangular spaces. By abandoning the longitudinal timbers in the fan over the shallow interior plate-girders, which the arrangement permitted, additional depth was obtained for these. The footpath platform on each side consists throughout of planking 6 in. thick, secured to the top of the cantilevers. The roadway platform is covered with tar pavement about 2 in. thick, and the footpath platforms with asphalte 1 in. thick. The longitudinals and the whole

of the planking are creosoted, and the latter is grooved and tongued with iron, and caulked with tar and oakum. The rails over the bridge are flat-bottomed, and of the ordinary section. On the outside of the footpath an ornamental railing, of cast-iron, is fixed, Figs. 1545 to 1548. A

1545.

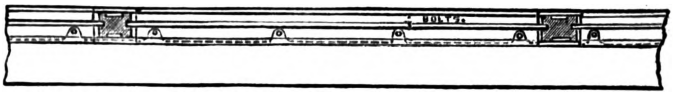



1546.




1547.

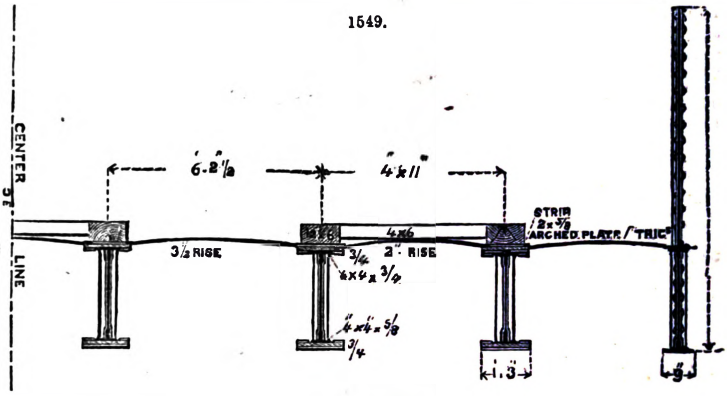
1548.



railing of a pattern generally similar is fixed to the main girders on the inside of the footpaths, to prevent the railway being trespassed upon.

On the Charing Cross railroad there are several small iron bridges, many similar to Broadwall Bridge, Figs. 1549 to 1553. This bridge consists of six inner working girders and two face-girders with a light parapet riveted to the upper flange. It has a span of 41 ft., and the depth of the girders is 2 ft. 6 in.; top flange, 16 in. wide by $\frac{3}{4}$ in. thick, riveted to web by two angle-irons, 4 in. × 4 in. × $\frac{3}{4}$ in., and pierced with holes for $\frac{7}{8}$ rivets every 3 in. on each side; bottom flange, 15 in. wide by $\frac{3}{4}$ in. thick, riveted to web by two angle-irons 4 in. × 4 in. × $\frac{5}{8}$ in.; web, $\frac{1}{4}$ in. thick in seven sections, connected at vertical joints by two T-irons, 5 × 2½ × $\frac{3}{4}$.

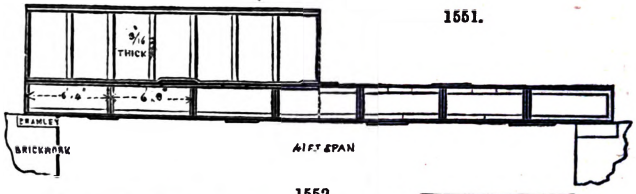
1549.




At each end of girder there is a bearing-plate. For face-girder, top flange, 9 in. wide by $\frac{1}{4}$ in. thick, not centred with web, to which it is connected by two angle-irons 3 × 3 × $\frac{1}{4}$.

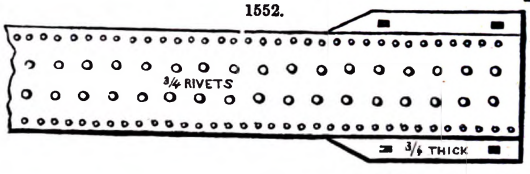
1550.

1551.



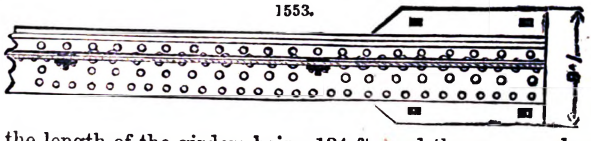

The girders in this bridge are braced by a system of diagonal bars, 3 in. × $\frac{5}{8}$ in., connected to girders by means of short pieces of T-iron, riveted to top and bottom of webs about 6 ft. 8 in. apart.

1552.




In addition to the ordinary angle-iron cover, a strip is riveted to the opposite side of the girder.

1553.



The weight of the six working girders is 26½ tons; of the two face-girders, 4½ tons; and of the whole bridge, 43 tons.

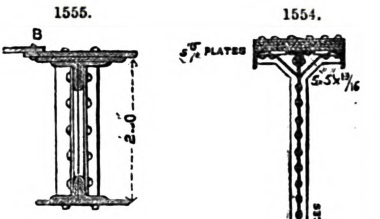
*Wellington Street Bridge.*—This, on the same line, is the largest single-web girder bridge on the line, the length of the girders being 134 ft., and the span on skew 118 ft. The girders are 12 ft. deep at centre, and 9 ft. 8 in. at the ends.

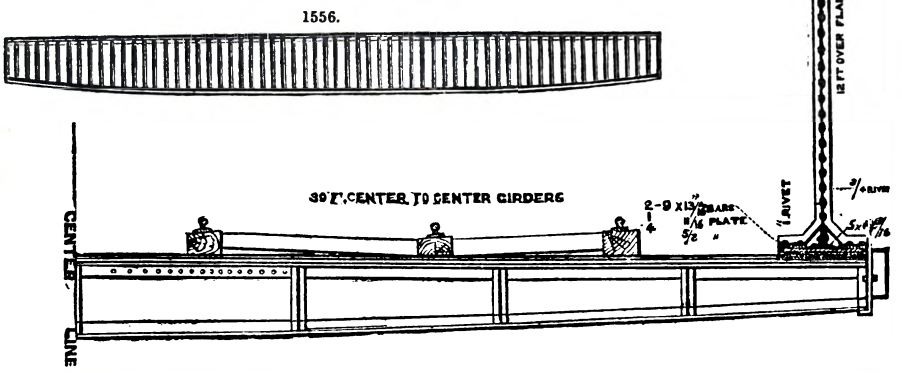
The flanges are 2 ft. 6 in. wide, riveted with six rows of 1-in. rivets. The top flange is built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends. In addition to the two angle-irons which connect this flange to web, there are two others of the same size, 5 × 5 × $\frac{13}{16}$, riveted to each edge, Figs. 1554, 1555. The bottom flange is built up of one $\frac{11}{16}$ and four $\frac{5}{8}$ plates, reduced at ends to one

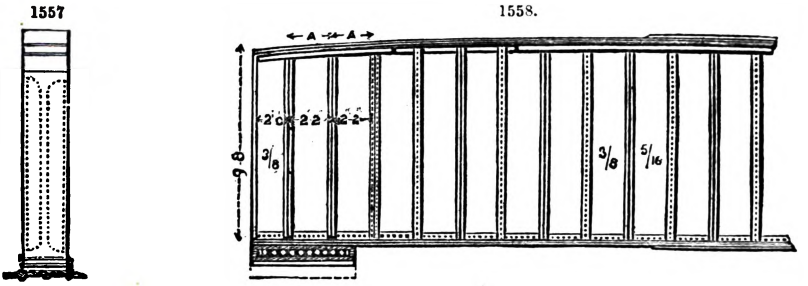
$\frac{11}{16}$ and two $\frac{5}{8}$ plates. On each side of the upper side of this flange a bar, 9 in. × $\frac{13}{16}$, is riveted. This is shown in Figs. 1554 to 1558. Fig. 1558 shows the way the plates break joint.

The web-plates, with the exception of the end ones, are 2 ft. 2 in. wide, the end ones being 2 ft. wide, as shown in Fig. 1558, $\frac{3}{8}$ thick for a length of nine plates at either end, and $\frac{5}{16}$ for the remaining distance.

Referring to Figs. 1556 to 1558, it will be seen that a $\frac{1}{4}$ plate is riveted to the ends of the girders by means of angle-iron *gussets*, 3 in. × 3 in. × $\frac{3}{8}$ in.; also, that at the two end web-joints $\frac{1}{4}$ *gusset*-plates are riveted, with similar angle-iron. After the bridge was erected, it was found necessary to stiffen the ends of the girders by




attaching reverse angle-iron, 3 × 3 × $\frac{1}{2}$, to the end and *gusset* plates. The intermediate vertical joints of web are connected by two T-iron gussets, 6 × 3 × $\frac{3}{8}$, and two strips, 6 × $\frac{3}{8}$ alternately. These strips, as shown in Fig. 1551, are cranked to set over the longitudinal angle-iron.

One end of each girder was provided with a bearing-plate, 5 ft. × 4 ft. × $\frac{3}{4}$; the other end had attached to it a cast-iron plate, 2 in. thick, to bear on eight rollers, 4½ in. diameter. The roller-beds are also of cast iron, 2 in. thick, and further strengthened by having three ribs, 3 in. deep, cast on; the roller-frames are of wrought iron, 3 in. ×

A longitudinal section of this roller arrangement is shown in Fig. 1558, and a transverse section in Fig. 1557.

In Fig. 1558 the lengths of top and bottom angle *covers* are shown by the number of rivets in each. The first have seven and eight holes in each arm respectively, and the second nine and ten; so that, since the rivets are 4-in. pitch, the lengths are 2 ft. 8 in. and 3 ft. 4 in.

The ordinary lengths of

| | | | |
|---|---|---|---|
| Angle-bars .. .. .. .. | 13 ft. | Joints to flat bars .. .. .. | 3 ft. 4 in. |
| Flat bars, 9 × $\frac{13}{16}$ .. .. .. | 17 ft. 4 in. | Laminated plates .. .. .. | 6 ft. 8 in. |

The dimensions A A, Fig. 1558, are 16 in. each, so that they contain four rivets in the direction of length of girder each. Considering one plate only, since there are six rows of rivets, we have an aggregate of twenty-four 1-in. rivets, or a sectional area of 18·84 sq. in. against 14·76 sq. in., the sectional area of a bottom plate through a line of rivet-holes; or an excess in area of rivets of 4·08 sq. in.

The cross-girders are 41 ft. 6 in. long, which makes the distance, centre to centre, of main girders 39 ft. The distance, centre to centre, of the cross-girders themselves, is 4 ft. They have a central and end depth of 2 ft. and 1 ft. 4 in.; the flanges are 15 in. × ½, connected to a ¼ web by 4 × 4 × $\frac{5}{8}$ angle-iron. The top flange has also riveted to it an extra plate, 19 × ¼, for attaching roadway plate. Fig. 1555 is a section of one of the girders, showing a road-plate attached at B. The length of the girder is divided into eight panels by vertical T-irons at joints, 5 × 2½ × $\frac{3}{8}$.

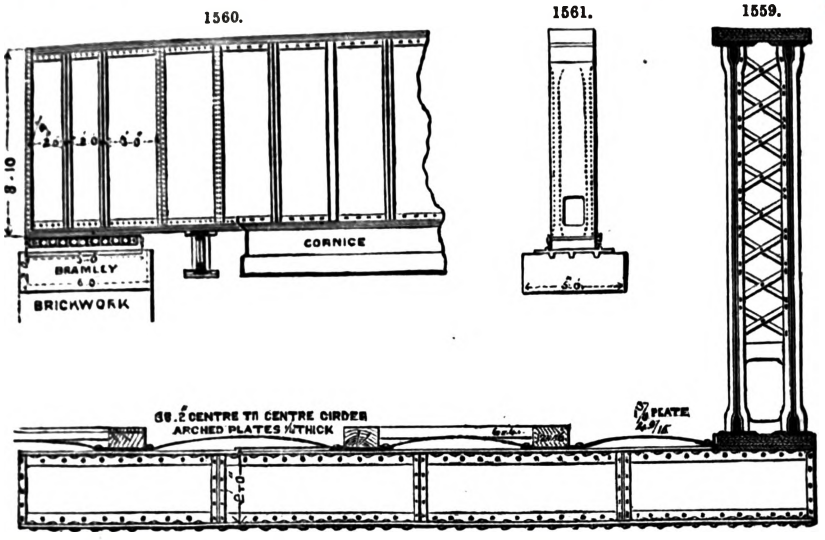
At each end of the bridge there are also shorter cross-girders; but they are the same as a 41 ft. 6 in. girder, with a piece cut off one end. The ends of the cross-girders are riveted to the mains with twenty-four rivets, 1 in. diameter.

To the ends of the cross-girder, a cast-iron cornice, C, Fig. 1554, is bolted.

The rivets through longitudinal angle-iron and webs are 1 in. diameter, and through vertical

T-irons, strips, and webs, only $\frac{7}{8}$ in. diameter. The weight of each main girder is 65 tons: of all the cross-girders, 80 tons; and of the whole bridge, 248 tons.

*Bridge over the Blackfriars Road*, Figs. 1559 to 1561.—One of the abutments of this bridge is at right angles to line, and the other only slightly out of square.




The main box-girders, which are 110 ft. long, have a central and end depth of 10 ft. 6 in. and 8 ft. 10 in.: both flanges are 2 ft. 6 in. wide; the top is built up of five $\frac{9}{16}$ plates at centre, reduced to four at ends; the bottom is built up of one $\frac{5}{8}$ and four $\frac{9}{16}$ plates at centre, reduced to one $\frac{5}{8}$ and three $\frac{9}{16}$ at ends. Each flange is connected to the webs by four angle-irons $6 \times 6 \times \frac{9}{16}$: eight in the whole section.

The two end web-plates at either end of each line are 2 ft. wide, and the intermediate ones are 3 ft.

The girders are braced internally at seven points by a system of lattice-bars, shown in Fig. 1559; the bars are $2 \times \frac{3}{8}$, and are riveted to T-irons, which, in this case, are substituted for the internal strips.

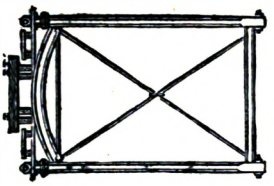
The cross-girders, twenty-four in number, have flanges 15 in. wide $\times \frac{1}{2}$ thick, riveted to a $\frac{1}{4}$ web by $4 \times 4 \times \frac{1}{2}$ angle-iron: they are 2 ft. deep, and each end is riveted to the main girder with twenty 1-in. rivets; the web is divided by vertical T-irons into eight panels.

The weight of both main girders is $106\frac{1}{4}$ tons; of all the cross-girders, 71 tons 12 cwt.; and of the whole bridge, 214 tons 17 cwt.

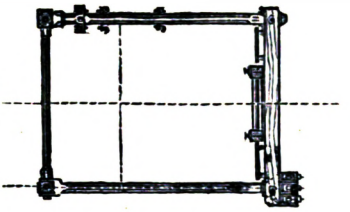
The roadway is on the second system, Fig. 1559.

The constructive arrangement of the bridge, exhibited in Figs. 1562 to 1569, introduced by Albert Fink, is a modification of the principles employed by Bollman. In this bridge a pair of diagonal tension-bars connect the foot of the principal strut, or *king post*, in each truss, with the ends of the top chord. This pair of diagonal bars support one half of the whole weight of the truss and its load. Each half-span is subdivided by a strut, and two diagonal tension-bars extend, one to the nearest end of the top chord, and the other to the top of the centre post. Each quarter-span is again subdivided into eighths, and these again, for spans greater than 100 ft., into sixteenths. In a truss of this kind, of sixteen panels, the weight at the bottom of the strut nearest to either of the piers is distributed thus:—Calling the weight one, one half is transferred directly through a tension-rod to the nearest end of the top chord, and to the pier. The other half is carried up to the top of the second strut from the pier, and is received at the bottom of that strut by a pair of tension-rods, which divide this half between them, one fourth being taken directly to the nearest pier, while the other fourth is transferred to the top of the strut at the quarter-span. This fourth is again divided at the foot of this strut, one eighth being transmitted through a tension-rod to the nearest pier, while the other eighth passes to the top of the middle strut of the span, and is received at the foot of this strut by the main tension-rods, each of which transmits one-sixteenth of the original load to each pier. Thus the weight at the foot of the first strut from the end of the truss is distributed thus:—One-half, one-fourth, one-eighth, and one-sixteenth, or, in all, fifteen-sixteenths of that weight reach the top of the nearest pier, through four converging sets of tension-rods, while the remaining sixteenth reaches the opposite pier, after being brought to the foot of the centre strut, through the intervention of three separate systems of tension-bars. With the exception of the load at the foot of the centre strut, which load is transmitted directly to the piers, the loads at the bottoms of the vertical struts are more or less subdivided before reaching the ends of the truss. In 1852, A. Fink erected a bridge of three spans, of 205 ft. each, across the Monongahela River, Figs. 1562 to 1569. The trusses for a single line are 16 ft. apart from centre to centre, and the main tension-chords are attached to the foot of the centre strut, 22 ft. 8 in. below the centre of the top chord, thus giving a depth of truss equal to 0·11 of the span. The top chords and the centre struts are of cast-iron pipes, octagonal in their external form, 12 in. diameter between their parallel surfaces, and 10 in. in internal diameter, thus giving 41 sq. in. of section. The main tension-rods in each truss are each formed of six bars, $4\frac{1}{2}$ in. by $1\frac{1}{4}$ in., giving

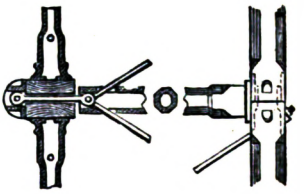
1563.



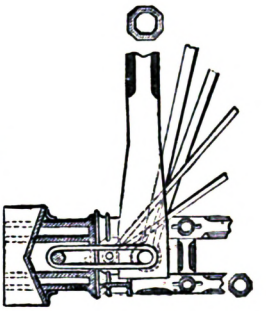
1565.



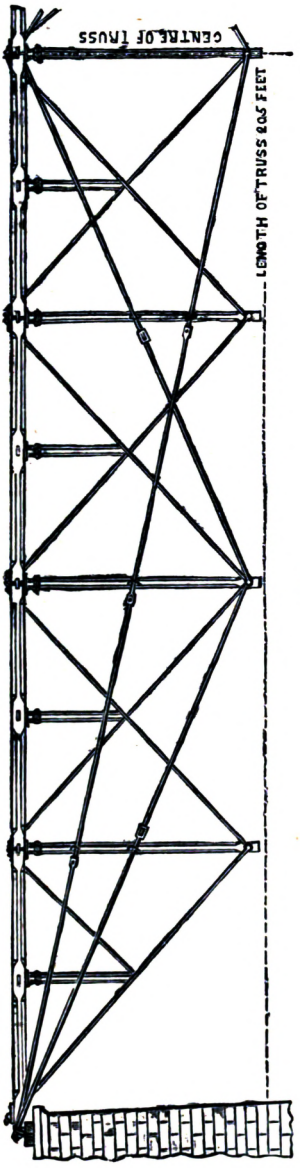
1569.



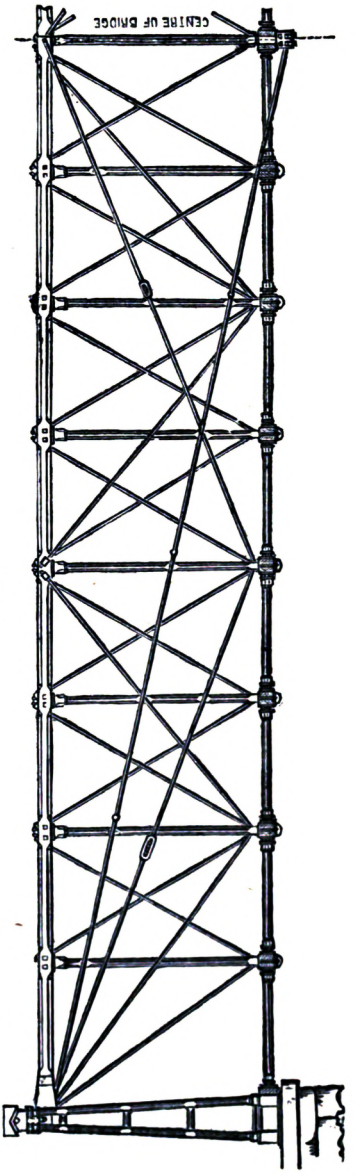
1568.



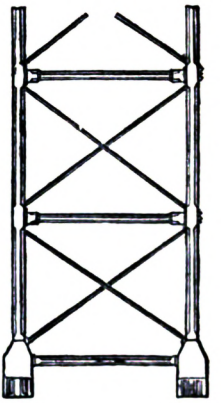
1562.



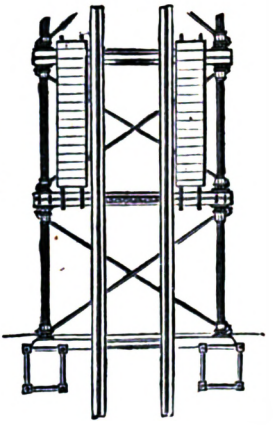

1564.




1567.

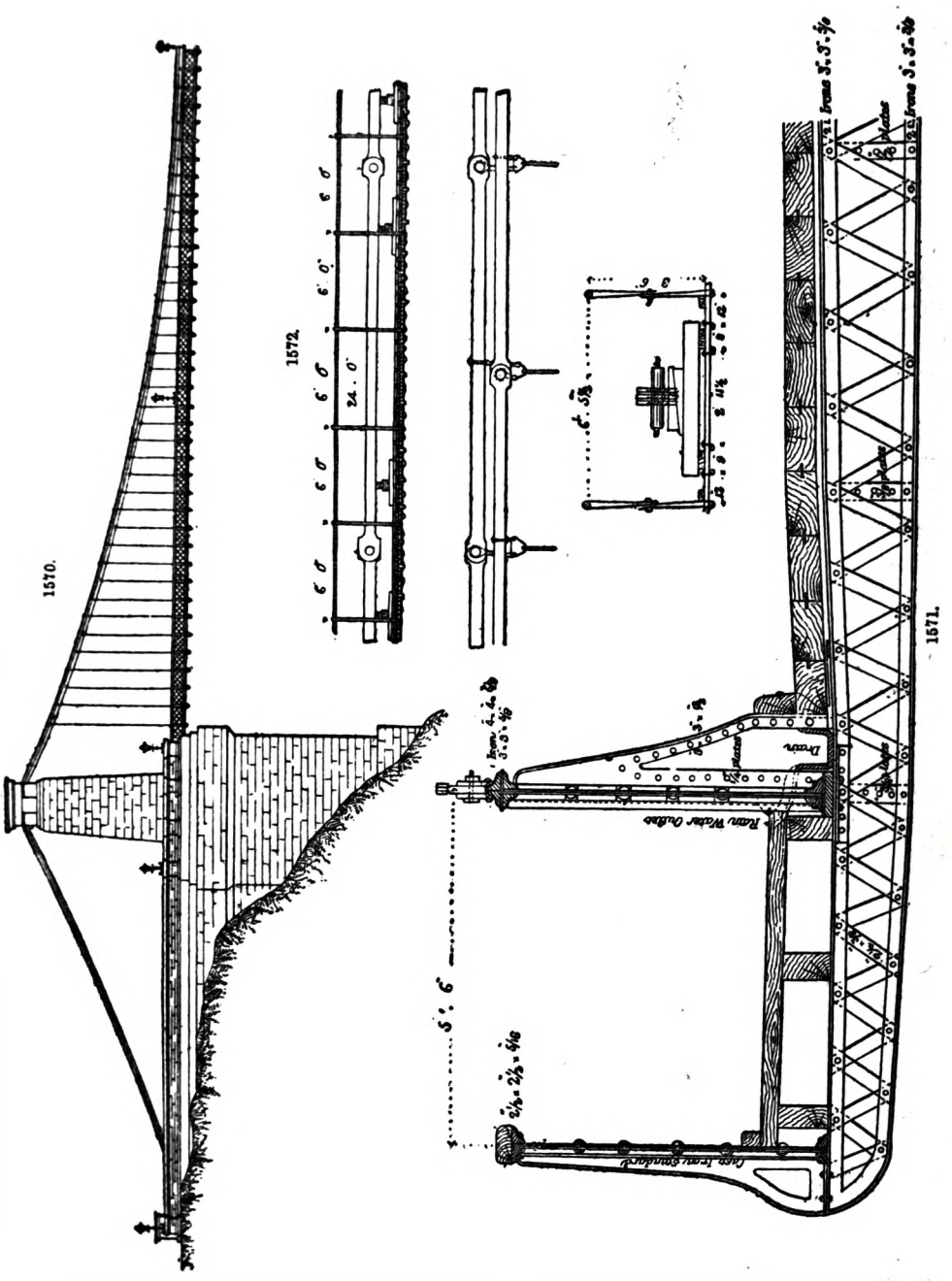


1566.



a section of 33¾ sq. in. The vertical struts, with the exception of the centre strut, are cast-iron octagonal pipes, 8 in. in external and 7 in. in internal diameter.

*Clifton Suspension Bridge.*—Excerpt Paper by William Henry Barlow, in 'Trans. Inst. C.E.,' 1867. In the Clifton Bridge as executed, Fig. 1570, there are three chains on each side, supporting longitudinal stiffening girders of wrought-iron, with open-work cross girders, the hand-railing of the bridge being made also to form longitudinal stiffening girders with open-work sides.




The principal dimensions of the bridge are—Span, 702 ft. 3 in.; distance from centre to centre of chains, 20 ft.; width of bridge, including roadway and footways, 31 ft.; versed sine of curve of chains, 70 ft.; height of roadway above high water, 248 ft. The roadway has a curve upwards, or camber, of 2 ft. between the piers.

The chains are carried upon the piers by wrought-iron saddles, placed on roller-frames of cast-iron, the rollers being made of cast-steel The beds of the roller-frames are at an inclination of 1 in 20, rising towards the risers. At a distance of 196 ft. from the centres of the piers, land-saddles are placed, which are similar in construction to the saddles upon the piers, except that they have no roller-frames, but are bedded upon brickwork in cement set upon the solid rock. From the land-saddle to the anchorage is a distance of 60 ft., with an average inclination of 45°. In this distance the three chains gradually diverge, until they become 5 ft. apart, where they are inserted through the castings which form the anchorage-plates. Each chain has a separate anchorage-plate, 5 ft. by 6 ft., bedded upon a mass of brickwork set in cement, built in plan in the form of an arch, abutting upon the solid rock.

The length of the links in the centre of the bridge, where they are horizontal, is 24 ft., increasing in length as their angles of inclination increase. The three chains are in such a relative position to each other as to produce an equal horizontal distance of nearly 8 ft. from the centre of the suspension-rods throughout the bridge.

The links in the Hungerford Bridge, Fig. 1572, were utilised in the erection of the Clifton Bridge, and were arranged so that the joints of the links in the upper chain were placed opposite to the middle of the links of the under chains; the suspension-rods were carried by a jointed link, in such manner that half the weight was borne at the point of the one chain, and the other half by the middle of the links of the other chain. In this mode of hanging the suspension-rods, a transverse strain of considerable amount was brought upon the middles of the links of the chains.

In the Clifton Bridge this has been avoided. The suspension-rods transmit their strain to the chains only at the joints. The result is, that the links of the chain have no other strain upon them than that of the direct tensile strain in the direction of their length. The duty of maintaining an equal action upon all three chains in supporting the roadway is performed by the strength and stiffness of the longitudinal girders. The suspension-rods are attached to the longitudinal girders in the manner shown by the diagram, Fig. 1570, each road being furnished with a double-adjusting screw at the lower extremity.

All the links of the Hungerford Bridge were tested to a strain of 10 tons a sq. in. before being erected in that bridge, and all the new links required to complete the third chain at Clifton have also been tested with a strain of 10 tons an in. The diameter of the bolts which connect the links together is $4\frac{3}{8}$ in.

The roadway is formed of a deck of 5-in. creosoted Memel planking, Fig. 1571, grooved and tongued with iron. Upon this is placed a second coating of planking transversely, which forms the wearing surface, and may be changed or varied in construction as the exigencies of the traffic may require. The footways are formed of $2\frac{1}{2}$-in. planking, laid upon longitudinal bearers.

The general arrangements made for the erection of the chain were as follows:—

A temporary suspended staging was constructed of eight iron wire ropes, each rope being capable of bearing 35 tons, Fig. 1572. Six ropes were placed beneath the planking, and two at a height of 3 ft. 6 in. above, the latter serving to form a hand-railing on each side. The upper ropes were attached to those below by hoop iron doubled over, and riveted, of sufficient strength to cause the upper ropes to act in conjunction with the ropes beneath the planking in sustaining any weight placed upon the staging. Above this staging another rope was fixed, for the purpose of carrying two light travelling frames suspended on wheels, which were moved as required by light ropes, and by means of which links were taken from the piers to the men engaged in erecting the chain.

The chains were commenced at the anchorage-plates at each end simultaneously, the lowest chain being put in first. At the anchorage-plates the whole of the links, twelve in number, were inserted; then eleven, ten, nine, eight, and so on until the chain was diminished to one link; after which it was continued at one link and two links alternately from the piers, until it met in the middle of the centre opening.

The wire-rope staging was designed to carry the weight of the centre portions of the chain, formed of one and two links alternately, with the men and tools required to erect it. The calculated breaking-weight of this staging was 224 tons, evenly distributed.

The weight it had to carry was 40 tons:—

| | Tons. |
|---|---|
| Chain formed of one and two links alternately | 12 |
| Workmen and tools (say) | 5 |
| Planking | 10 |
| Wire ropes | 8 |
| Bolts, nuts, and sundries, including packing for links | 5 |

or less than $\frac{1}{8}$th of the breaking-weight.

The suspended platform was kept below the intended level of the chain, and the links were supported upon it by packing pieces, which could be raised or lowered. When the links of the chain were united in the middle, the packing pieces upon the staging were lowered until the chain took its own bearing, and thus relieved the staging from the action of its weight. At this stage of the proceedings the chain was adjusted for length by means of keys arranged for that purpose in the first links from the pier-saddles.

The next operation was that of adding links on each side of the centre links, which was rapidly accomplished by an ingenious and simple apparatus. The rapidity with which the side links were added depended much upon the state of the weather; but there were some days on which more than one hundred links were added to the chain.

In connection with the temporary staging, there were many other pieces of apparatus or contrivances for winding, tightening, and fastening, which were excellently carried out.

The chains on the Bristol or eastern side of the bridge having been completed, the staging was shifted over to the other side, and the remaining three chains were put up in like manner.

When the chains were complete, and the suspension-links for carrying the suspension-rods were

fixed, the next operation was that of attaching the suspension-rods and cross-girders. This was accomplished by an apparatus made for the purpose, consisting of a movable crane, upon a long base frame, weighing rather over 5 tons, and travelling upon a temporary railway. It was so contrived and balanced that it could carry the weight of a cross-girder, with a portion of the longitudinal girders attached, at a considerable distance in advance of the wheels upon which it travelled. Thus, when placed upon the abutment, it held the first cross-girder in its intended position until the men attached the first pair of suspension-rods to it and to the chain. Planking was then laid from the abutment to the cross-girder, and the railway was lengthened. The travelling-crane then took up the second cross-girder, and advanced with that to its position, and held it in like manner until it was attached to the chain. The planking and roadway were again lengthened, and the third cross-girder fixed, and so on from both ends of the bridge, until the roadway met in the middle.

The remaining operations of connecting the longitudinal girders, adjusting the several parts of the work, and laying the roadway, were then proceeded with.

The manner in which the weights were of necessity brought upon the chain, commencing as they did from the abutments and proceeding towards the centre of the opening, caused the curve of the chain to vary in figure very much during the construction; but the ultimate curve, which resulted when the roadway was completed, accords with remarkable accuracy to the calculated curve, and the calculated lengths of the several suspension-rods.

The sectional area of the chains at the piers is 481 sq. in., and in the centre of the span 440 sq. in. The weight of the chains between the piers is 554 tons. The strain produced at the centre of the chains by the weight of the chains themselves is nearly 680 tons. The weight of the suspension-rods, longitudinal girders, transverse girders, cross-bracing, hand-railing, roadway, and so on, is about 440 tons. This weight is not spread over the whole of the 702 ft. span, but occurs between the abutments which project in front of the piers, leaving a space between them of 636 ft. The distance of the centre of gravity of the half span of the platform from the centre of the pier is 190 ft. nearly. The strain produced by the weight of the platform at the centre of the chains is 597 tons approximately. The maximum moving load, estimated at 70 lbs. a sq. ft., or 600 tons upon the platform of the bridge, would produce a strain of 817 tons at the centre of the chain.

The total strain at the centre would therefore be as follows:—

| | Tons. |
|---|---|
| Strain due to the chains .. .. .. .. .. .. .. .. .. .. | 680 |
| „ to the weight of the platform rods, &c. .. .. .. .. .. | 597 |
| „ to the load of 70 lbs a square ft. upon the platform .. ... | 817 |
| Total .. .. .. .. .. ... .. .. .. .. | 2094 |

To carry this strain there are 440 sq. in. of metal, so that the maximum strain upon the iron is $\frac{2094}{440} = 4{\cdot}76$ tons a sq. in.; of which the strain produced by the bridge itself is 2·90 tons a sq. in.

It is to be observed that the piers, although the same height above the abutments, are not level with each other. The pier on the Leigh Wood side is 3 ft. lower than that on the Clifton side, and the whole bridge has an average inclination of 1 in 233. This inclination was given to the structure by Brunel to obviate what he thought would have been an ocular deception, had the bridge been horizontal, arising from the difference in the height and form of the rocks on the two sides of the river. This peculiar arrangement makes a difference in the strains upon the chains in the two halves of the bridge, and in the form of the curve of the chain, which had to be calculated and provided for in the lengths of the suspension-rods. The calculations for the form of the curve, and the lengths of the respective parts, were made by Alfred Langley; and it is satisfactory to add that there was not a single rod or part of the bridge which had to be altered in execution.

The suspension-rods are each rather more than 2 in. in section. The greatest weight that can come upon a pair of rods, including their maximum load, is about 13 tons, which would produce a strain of 4¼ tons a sq. in.

The brickwork employed in the anchorage and land-saddles is of Staffordshire blue bricks, laid in Portland cement, and the anchorage-plates and the bearing-plates of the saddles are so arranged that the maximum pressure upon the brickwork cannot in any case exceed 10 tons a sq. ft.

The bridge is stiffened longitudinally by two plate-girders, 3 ft. deep, placed on each side of the roadway, the upper and lower flanges of these girders being 11 in. in sectional area. The hand-railing, which is in effect a lattice-girder, 4 ft. 9 in. deep, with upper and lower flanges of 4½ in. sectional area, also adds to the stiffness of the bridge. Both these girders act in giving stiffness against a horizontal transverse strain, and are assisted in that action by a system of diagonal bracing throughout the bridge, formed of bars 4 in. by ½ an in. in section placed beneath the roadway.

In order to provide for the effects of expansion and contraction, and to allow for the movement occasioned by wind and by the passage of heavy loads across the bridge, the two extremities of the roadway are furnished with jointed ends or flaps, 8 ft. long, which give perfect freedom of motion both vertically and in the direction of the length of the bridge.

Previous to opening the bridge for public traffic, it was tested by a dead-weight of 500 tons of stone distributed over the surface. The total deflection produced by the test-load was 7 in. in the centre of the bridge, which deflection resulted not only from the elongation of the metal due to the stress, but also from the altered position of the saddles upon the piers, arising from the diminished curvature of the land chains. When the test-weight was removed, the centre of the bridge rose again to its former position within $\frac{1}{16}$th of an in., but the middle of the southern half of the bridge did not rise again to its former height by 1 in., while the northern side rose above its original position. This circumstance was probably due to the change in the direction and force of the wind before and after the testing.

The following is a tabular statement of the results of the testing above referred to ;—

CLIFTON SUSPENSION BRIDGE.

TABLE showing the Deflections produced by the Test Load of 500 Tons evenly distributed.

| South Chain. | | | | | North Station. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of Suspension Rod. | Level before the Load was put on. | Level with the full Load of 500 Tons. | Level after the Load was removed. | Permanent Set. | Number of Suspension Rod. | Level before the Load was put on. | Level with the full Load of 500 Tons. | Level after the Load was removed. | Permanent Set. |
| | Feet. | Feet. | Feet. | | | Feet. | Feet. | Feet. | |
| Leigh Wood side 1 | 4·77 | 4·73 | 4·76 | − ·01 | Leigh Wood side 1 | 4·78 | 4·75 | 4·77 | − ·01 |
| 6 | 3·94 | 3·98 | 3·95 | + ·01 | 6 | 3·90 | 3·95 | 3·88 | − ·02 |
| 11 | 3·33 | 3·48 | 3·37 | + ·04 | 11 | 3·28 | 3·44 | 3·31 | + ·03 |
| 16 | 2·75 | 3·02 | 2·83 | + ·08 | 16 | 2·72 | 3·00 | 2·76 | + ·04 |
| 21 | 2·22 | 2·62 | 2·28 | + ·06 | 21 | 2·18 | 2·58 | 2·26 | + ·08 |
| 26 | 1·75 | 2·24 | 1·83 | + ·08 | 26 | 1·66 | 2·18 | 1·75 | + ·09 |
| 31 | 1·40 | 1·97 | 1·46 | + ·06 | 31 | 1·25 | 1·82 | 1·33 | + ·08 |
| 36 | 1·10 | 1·72 | 1·15 | + ·05 | 36 | 0·92 | 1·55 | 0·98 | + ·06 |
| 41 | 0·92 | 1·54 | 0·94 | + ·02 | 41 | 0·75 | 1·35 | 0·75 | ·00 |
| | | | | Centre rod. | | | | | Centre rod. |
| 41 | 4·00 | 4·59 | 4·01 | + ·01 | 41 | 3·82 | 4·40 | 3·83 | + ·01 |
| 46 | 3·90 | 4·48 | 3·93 | + + ·03 | 46 | 3·70 | 4·28 | 3·71 | + ·01 |
| 51 | 3·90 | 4·40 | 3·90 | ·00 | 51 | 3·72 | 4·21 | 3·73 | + ·01 |
| 56 | 3·92 | 4·33 | 3·93 | + ·01 | 56 | 3·75 | 4·13 | 3·75 | ·00 |
| 61 | 3·98 | 4·31 | 4·02 | + + + ·04 | 61 | 3·83 | 4·13 | 3·84 | + ·01 |
| 66 | 4·10 | 4·34 | 4·15 | + + ·05 | 66 | 4·02 | 4·21 | 4·02 | ·00 |
| 71 | 4·32 | 4·44 | 4·32 | ·00 | 71 | 4·22 | 4·31 | 4·21 | − ·01 |
| 76 | 4·50 | 4·51 | 4·49 | − ·01 | 76 | 4·50 | 4·47 | 4·44 | − ·06 |
| Clifton side . 81 | 4·90 | 4·84 | 4·88 | − ·02 | Clifton side . 81 | 4·95 | 4·83 | 4·89 | − ·06 |
| | | Saddles on piers travelled forward. 1⅛″. | Saddles travelled back again, ⅛″. | | | | Saddles on piers travelled forward, 1⅛″. | Saddles travelled back again, ⅛″. | |

Since the completion of the bridge it has had to sustain large and irregular-moving loads. Being a work of great local interest, it has on several occasions been crowded with people. It is evident, however, that the most severe strain which it will have to resist is that resulting from heavy gales of wind. South-westerly gales blow nearly in the direction of the length of the bridge, and the high ground on either side diminishes their effect upon the structure. But gales from the north-west or south-east, being nearly in the direction of the deep gorge of the River Avon at the place where the bridge is constructed, impinge upon the work with great violence, so much so that it is difficult at times to stand upon the roadway. On these occasions three effects are observed :

First, there is a small horizontal deflection, which is just sufficient to be perceptible to the eye when placed in range with the suspension-rods. Secondly, there is an undulation from end to end of the bridge. It is a slow and steady movement of the structure, which manifests itself by a rising

TABLE of EXPERIMENTS on CAST-IRON BEAMS, showing the Weight on the CENTRE SPAN at the TIME of FRACTURE.

| Condition of Loading. | No. 1. Uniform Continuous Beam, 1 inch square, 15 feet long, supported at the ends, and on piers 4 feet 6 inches on each side the centre. | No. 2. A similar Beam, increased three times in width over the piers, the weight of Beam being increased 50 per cent. | No. 3. A similar Beam increased to double the depth over the piers, the weight of Beam being increased 25 per cent. | Detached Beam, 1 inch square, loaded uniformly. Length of bearing 6 feet, equal to centre span of Beams, Nos. 1, 2, 3. |
|---|---|---|---|---|
| Loaded only on centre span, the ends being fastened down. | Exp. lbs.<br>No. 1 1,0·032<br>„ 2 1,254·4<br>„ 3 1,186·4<br>„ 4 1,054·2<br>Mean 1,131·75 | Exp. lbs.<br>No. 1 1,567·2<br>„ 2 1,656·0<br>„ 3 1,567·2<br>„ 4 ..<br>Mean 1,596·8 | Exp. lbs.<br>No. 1 1,569·6<br>„ 2 1,836·0<br>„ 3 1,636 2<br>„ 4 1,658·4<br>Mean 1,675·05 | lbs.<br>Experiment No. 1 . . 696·0<br>„ „ 2 . . 717·6<br>„ „ 3 . . 662·1<br>„ „ 4 . . 494·4<br>Mean . . . . 642·52 |
| The load a foot on centre span being twice that on side spans. | Exp. lbs.<br>No. 1 1,411·4<br>„ 2 1,637·6<br>„ 3 1,433·6<br>„ 4 1,411·4<br>Mean 1,473·5 | Exp. lbs.<br>No. 1 1,882·4<br>„ 2 2,107·2<br>„ 3 1,726·4<br>„ 4 1,949 0<br>Mean 1,916 25 | Exp. lbs.<br>No. 1 2,062·4<br>„ 2 2,712·8<br>„ 3 2,916·8<br>„ 4 2,420·0<br>Mean 2,528·0 | Summary showing the Breaking Weights as compared with a detached Beam. |
| Beam loaded uniformly over its whole length. | Exp. lbs.<br>No. 1 1,413·4<br>„ 2 1,300·8<br>„ 3 1,233·6<br>„ 4 1,277·6<br>Mean 1,306·35 | Exp. lbs.<br>No. 1 2,465·6<br>„ 2 2,284·8<br>„ 3 1,972·8<br>„ 4 2,356·0<br>Mean 2,269·8 | Exp. lbs.<br>No. 1 2,556·8<br>„ 2 3,212·4<br>„ 3 2,510·4<br>„ 4 3,094·4<br>Mean 2,843·5 | |

| Condition of Loading. | No. of Beam. | Mean relative Strength of each Form of Beam, that of Detached Beam being 1. |
|---|---|---|
| Loaded only on centre span, the end being fastened down . . . . | 1 | 1·7614 |
| | 2 | 2·4853 |
| | 3 | 2·6070 |
| The load a foot on centre span being twice that on side spans . . . . | 1 | 2·1967 |
| | 2 | 2·9824 |
| | 3 | 3·9346 |
| Beam loaded uniformly over its whole length . | 1 | 2·0328 |
| | 2 | 3·5327 |
| | 3 | 4·4256 |

TABLE showing the DEFLECTIONS with 100 lbs. uniformly Distributed over CENTRE SPAN.

| Condition of Loading. | No. 1. Uniform Continuous Beam. | No. 2. Continuous Beam, increased three times in width over the Piers the weight of Beam being increased 50 per cent. | No. 3. Continuous Beam increased to double the depth over the Piers, the weight of Beam being increased 25 per cent. | Detached Beam loaded uniformly. Length of bearing equal to centre span of Beams, Nos. 1, 2, 3. |
|---|---|---|---|---|
| Loaded only on centre span, the ends being fastened down. | Exp. inch.<br>No. 1 . ·1703<br>„ 2 . ·1572<br>„ 3 . ·1501<br>„ 4 . ·1669<br>Mean . ·1611 | Exp. inch.<br>No. 1 . ·1308<br>„ 2 . ·1274<br>„ 3 . ·1381<br>Mean . ·1321 | Exp. inch.<br>No. 1 . ·1114<br>„ 2 . ·1090<br>„ 3 . ·1066<br>„ 4 . ·1187<br>Mean . ·1114 | inch.<br>Experiment No. 1 . . . ·3555<br>„ „ 2 . . . ·3296<br>„ „ 3 . . . ·3640<br>„ „ 4 . . . ·3505<br>Mean . . . . . ·3499 |
| The load a foot on centre span being twice that on side spans. | Exp. inch.<br>No. 1 . ·1428<br>„ 2 . ·1317<br>„ 3 . ·1317<br>„ 4 . ·1246<br>Mean . ·1327 | Exp. inch.<br>No. 1 . ·0979<br>„ 2 . ·0935<br>„ 3 . ·0916<br>„ 4 . ·0955<br>Mean . ·0946 | Exp. inch.<br>No. 1 . ·0795<br>„ 2 . ·0788<br>„ 3 . ·0723<br>„ 4 . 0723<br>Mean . ·0757 | Summary showing the Deflection as compared with a detached Beam. |
| Beam loaded uniformly over its whole length. | Exp. inch.<br>No. 1 . ·0843<br>„ 2 . ·0823<br>„ 3 . ·0799<br>„ 4 . ·0799<br>Mean . 0816 | Exp. inch.<br>No. 1 . ·0496<br>„ 2 . ·0477<br>„ 3 . ·0472<br>„ 4 . ·0497<br>Mean . ·0485 | Exp. inch.<br>No. 1 . 0228<br>„ 2 . 0250<br>„ 3 . 0239<br>„ 4 . ·0283<br>Mean. ·0250 | |

| Condition of Loading. | No. of Beam. | Mean relative Deflections, that of detached Beam being 100. |
|---|---|---|
| Loaded only on centre span, the ends being fastened down . . | 1 | 46·04 |
| | 2 | 37·75 |
| | 3 | 31·83 |
| The load per foot on centre span being twice that on side spans . | 1 | 37·92 |
| | 2 | 27·04 |
| | 3 | 21·63 |
| Beam loaded uniformly over its whole length . | 1 | 23·31 |
| | 2 | 13·86 |
| | 3 | 7·14 |

and falling on the roadway about half-way between the centre and the abutments, alternating from the north-eastern to the south-western portion of the bridge. The third effect produced by wind is the motion imparted to the land chains. It will be observed that there are no suspension-rods between the piers and the land-saddles, so that the chains hang without anything to restrain their motion. Violent gusts of wind are capable of deflecting these chains laterally, notwithstanding their weight, the longitudinal strain upon them, and the comparatively small surface exposed.

Two features of this bridge appear worthy of remark. One is the facility with which the work was executed; the other is the comparatively inexpensive nature of the scaffolding or temporary staging required for erecting the chains, considering the distance between the points of support. Both these results are due to the principle of suspension. Already spans crossed by bridges on the principle of suspension far exceed those of any form of girder.

In relation to this subject it may be right to mention a construction of continuous girder which approaches, in regard to economy of materials employed, to a stiffened suspension bridge. In a continuous girder, if, instead of using an equal depth throughout, a greater depth and a greater sectional area be given over the piers, it has been found by experiments on solid bars, as well as from a theoretical investigation of the case as applied to lattice girders, that an increase of strength is obtained in a much higher ratio than that of the increased weight of metal employed. The experiments on the bars referred to were made by W. H. Barlow, in 1858, and the material employed was cast-iron, which was selected because the relative strengths of the different forms were indicated in a distinct and decided manner, by the actual rupture of the beam. The experiments extended to a comparison of strengths and stiffness of four descriptions of bars;—

1st. Detached bars, parallel throughout. 2nd. Continuous bars, of equal section throughout. 3rd. Parallel continuous bars, in which the sectional area was increased over the piers, without increasing the depths. 4th. Continuous bars, in which both the sectional area and the depth were increased over the piers. The continuous bars were tried under three separate conditions of loading;—1st. The centre span alone was loaded. 2nd. The load on the centre span per unit of length was made double the load in the side spans. 3rd. The load was evenly distributed throughout the whole length of the bar. The detached bar was 6 ft. between the bearings; the continuous bars were 15 ft. long, having a centre opening of 6 ft., and two side openings, each 4 ft. 6 in. The results are given in the p. 764 tables.

In the last form, where the area and the depth are each made double over the pier, while the bar is increased in weight only 25 per cent. in the centre opening, the strength and stiffness are increased in much higher proportion.

The mean relative strength of this bar, in the three conditions of loading, that of the detached bar being taken as 1, were as follows;—when loaded only in the centre span, 2·60; when the load a foot on the centre span was twice that of the side span, 3·93; when the load was equally distributed throughout the bar, 4·42. The stiffness was increased in a still higher proportion, for, taking the deflection of a detached beam at 100, the deflections of the continuous beams under the three conditions of loading, were 31, 21, and 7 respectively.

The introduction of a material of twice the tensile strength of iron would enable a bridge of twice the span of the Clifton Bridge to be made with the same sectional area in the chains, the ratio between the versed sine of the curve and the length of the chains being similar, and the weight of the roadway and load a foot the same in each case; whereas to make a bridge of double that span in wrought-iron would require nearly four times the section in the chains. The importance of so great a reduction in weight in crossing openings of large span can hardly be overrated. It operates not only in diminishing the actual quantity of material in the structure itself, and the consequent strains on the abutments or anchorages, but it diminishes very greatly the cost of the temporary staging and scaffolding required to construct the work.

### Comparative merits of different Systems of Iron Bridge Building accurately examined.

*Taken from Jules Gaudard's excellent work, 'Étude Comparative de Divers Systèmes de Ponts en Fer.'*

*General Symbols.*

$\mathbf{M}$ = Moment of rupture, or moment of resistance which is equal to it;
$\mathbf{F}$ = Stress or transverse strain;
$\mathbf{R}$ = Resistance the square mètre (6000000 for tension or compression, 4000000 for shearing strain) (see No. 18);
$p$ = Permanent continuous load, the lineal mètre of girder;
$p'$ = Moving load, the lineal mètre of girder;
$q$ = Proportion $\frac{p'}{p+p'}$ of the moving to the whole load;
$\mathbf{P}$ = Sometimes a weight applied to a certain point of a girder, sometimes the weight of the girder itself in its length of bearing;
$l$ = Bearing of the girder;
$\mathbf{L}$ = Length of the girder;
$\frac{\mathbf{P}}{l}$ = Mean weight of girder, the lineal mètre (see No. 37);
$\frac{\mathbf{PL}}{l}$ = Weight of the girder;
$d$ = Void between the abutments;
$\frac{\mathbf{PL}}{ld}$ = Weight the lineal mètre of girder spanning the void;
$\delta$ = Interval between two successive points to which the load is applied, in girders loaded in a discontinuous manner;

$N = \frac{}{\delta}$;

$m = \frac{l}{2\delta}$ or $\frac{l-\delta}{2\delta}$, according as $\delta$ enters an even or an odd number of times into $l$;

$n$ = Number indicating the order of a section of flange or a lattice-bar, the numbering beginning at the middle of the bearing;

$\alpha$ = Angle of inclination of the struts;

$\beta$ = Angle of inclination of the ties;

$h$ = Height of the girder:

$t$ = Weight the lineal mètre of a prism capable of supporting a strain of 1 kilogramme, or proportion of the weight of a cubic mètre to the resistance per square mètre. For iron $t = \frac{7800^k}{6000000} = 0{\cdot}0013$;

U = Coefficient applied to the flanges, the actual weight of which is always greater than the theoretical weight (see Nos. 63 and following);

V = Mean coefficient of stiffness applied to compressed bars (see Nos. 68 and following);

$\Omega$ = Supplementary term taking into account the weight of various accessories independent of $h$.

The dimensions of an iron plate are denoted by the symbol $a/b$, the letters $a$ and $b$ being replaced by numbers indicating respectively the breadth and the thickness of the section.

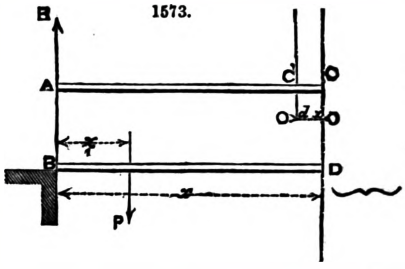
For an angle-iron, we write $a/b/c$ or $\frac{a/b}{c}$, $a$ and $b$ being the breadth of the arms, and $c$ the mean thickness; for a simple T, $\frac{a/b}{c/d}$, $a$ being the total breadth of the double arm and $c$ its thickness, $b$ the length of the single arm (including the thickness $c$), and $d$ its thickness.

For a double T rolled, $\frac{a/b}{c/d}$, $a$ being the total height, $c$ the thickness of the web, $b$ the breadth of the flanges, and $d$ their thickness; and, generally, for a double T, consisting of plate and angle iron, we indicate successively the dimensions of the web, one of the four angle-irons, and one of the flanges.

When angle-iron with arms of unequal length is used, the lesser arm is applied to the plate and bears the bolts, and the greater forms the projecting mouldings or flanges.

1. *Moments of Rupture and Transverse Strain for Girders resting freely upon Two Supports.*—Let us consider, Figs. 1573, 1574, a portion A B C D of a girder included between any section C D and a support B, and subjected to various loads or vertical forces, as P. The reaction of the abutment is a force R also vertical. The reactions exerted at C D may be reduced to a force F and a couple. The other forces being vertical, F must be vertical also: it is in equilibrio with the vertical transverse strain in the section considered, the value of which is $F = R - \Sigma P$, the sign $\Sigma$ indicating a sum. The condition of equilibrium relative to the moments of the forces requires that the moment of the couple, or *moment of resistance* of the section C D, should be equal to the moment of the other forces with respect to this same section. This latter moment, called *moment of rupture*, has the value $M = R\,x - \Sigma P(x - x_1)$. Its differential $\frac{dM}{dx} = R - \Sigma P$ = transverse strain.

1573.




1574.

The vertical rib, or web of the girder, is besides subjected to a sliding strain upon its longitudinal fibres or horizontal transverse strain. Indeed, if we conceive the fragment C O O' C', limited by two sections infinitely near C O, C' O', and by a horizontal fibre O O', this fragment is subjected, upon C O, to a certain pressure T, and upon C' O' to T + $dT$; the resultant $dT$ ought to be held in equilibrio by a force of adhesion $R_1 e\,dx$ upon O O' ($e$ = thickness of the web, $R_1$ = resistance to shearing strain.

The maximum of this action occurs when O O' is situate upon the neutral axis; for then T is resisted by the force of all the compressed fibres situate above this axis. As the flange has a section usually greater than the rib, and, besides this, contains the fibres which are most acted upon, the point of application of the resultant T will be very near the flange, and its value will be approximatively equal to the moment of rupture M divided by the height $h$ of the girder. Consequently we shall have $dT = \frac{dM}{h} = R_1 e\,dx$, whence $e = \frac{dM}{dx} \cdot \frac{1}{R_1 h} = \frac{F}{R_1 h}$, which may be explained by saying that the vertical section $e\,h$ of the rib should be capable of resisting a shearing force equal to the transverse strain, a condition which enables us to calculate the thickness $e$.

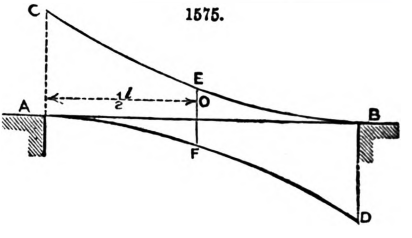
2. *Moment of Rupture and Transverse Strain due to a Load uniformly distributed.*—If the load $p$ per lineal mètre extends throughout the whole length of bearing $l$, the figure of the moments of rupture will be the parabola $M = \frac{1}{2} p\,x\,(l - x)$, the abscissæ being reckoned from the abutment. This parabola has its axis vertical, and the value of its parameter is $\frac{2}{p}$; the maximum moment in the middle of the bearing is $\frac{p\,l^2}{8}$. The transverse strain is represented by the right line having

for equation $F = p\left(\frac{l}{2} - x\right)$; it is = 0 in the middle of the bearing. Considering the beginning of the co-ordinates in the middle of the girder, we should have $M = \frac{p}{2}\left(\frac{l^2}{4} - x^2\right)$ and $F = -p\,x'$.

3. Let us now consider a load $p'$ per lineal mètre, uniformly distributed as $p$, but extending only over a portion of the bearing included between the fixed abscissæ $x = a$, and $x = a + b$, reckoned from the left abutment. Then, in the first interval, of length $a$, the moment of rupture due to $p'$ will be represented by a right line $M = \frac{p'b}{2l}(2l - 2a - b)\,x$; in the second interval, of length $b$, by an arc of a parabola tangential to the preceding right line, and expressed by $M = \frac{p'b}{2l}(2l - 2a - b)\,x - \frac{1}{2}p'(x - a)^2$; and in the third interval, of length $l - a - b$, by a new tangent to the parabola, namely, $M = \frac{p'b(2a + b)}{2l}(l - x)$. The figure of the transverse strains is a broken line, the extreme portions of which are horizontal.

For the maximum of the moment of rupture $p'$ must extend over the whole bearing; but for the maximum of strain at the point, the abscissa of which is $x$, $p'$ must lie only between this point and the most distant support. If it lies between the point in question and the right abutment, the force is positive, if we consider as positive those forces which act upwards; it is expressed by $F = \frac{p'}{2l}(l - x)^2$, and is consequently represented by an arc of a parabola, the ordinate of which upon the left support is $A\,C = \frac{p'l}{2}$, Fig. 1575, the ordinate in the middle $O\,E = \frac{p'l}{8}$, and the ordinate at $B = 0$; this latter point is the summit of the parabola. When, on the contrary, the load is placed upon the length included between A and the point the abscissa of which is $x$, we have as the figure of the straining forces, then negative, another parabola A F D, having its summit in A, and the maximum ordinate of which, absolutely expressed, is $-B\,D = -\frac{p'l}{2}$. Thus the load $p'$, by changing its position, produces at each point of the bearing transverse strains sometimes positive, sometimes negative.

1575.




4. In brief, if we have at the same time a dead weight $p$ and a moving weight $p'$, the maximum moment of rupture will be $M = \frac{1}{2}(p + p')\,x(l - x)$, and the transverse strain in the left half bay $F = \frac{1}{2}(p + p')(l - 2x) + \frac{p'x^2}{2l} = \frac{1}{2}(p + p')\left(l - 2x + \frac{x^2}{l}q\right)$, $q$ denoting the proportion of the moving weight $p'$ to the total weight $p + p'$.

The value of the area comprised between the figure of the moments of rupture and the axis of the $x$'s is $\frac{1}{12}(p + p')\,l^3$, and the area of the maximum straining forces, absolutely expressed, is $\frac{1}{4}(p + p')\,l^2\left(1 + \frac{1}{6}q\right)$ for the whole bearing. Dividing these areas by $l$, we shall have the mean ordinates of the moments of rupture and of the maximum straining forces. Sometimes the effects do not depend exclusively upon F or M, but upon a function of the form $B\,F - A\,M$. Now if we consider only $p'$, this function will be greatest when $p'$ extends between the point considered and the farthest abutment; it will then attain the value $\frac{p'(l - x)^2}{2l}(B - A\,x)$.

5. *Effect of Loads uniformly distributed at certain intervals.*—When a girder supports discontinuous weights P, P′ P″, . . . applied to points having as their abscissæ $a$, $a + b$, $a + b + c$, and so on, and such that $P = \frac{1}{2}p(a + b)$, $P' = \frac{1}{2}p(b + c)$, and so on, the figure of the moments of rupture is a polygon inscribed in the parabola which would correspond with a load $p$ per lineal mètre, uniformly distributed over all the parts of the girder.

Supposing each of the extreme intervals equal to $a$, all the intermediate intervals to $\delta$, and $l = 2a + N\,\delta$, the permanent weights applied to the points of division will be equal to $p\,\delta$, except at the extreme points, where they will be $\frac{1}{2}p(a + \delta)$. The load $p'$ will furnish analogous weights, but they can be only on a certain number of consecutive points of division. The transverse strain for a given load is constant in each interval, but varies from one to the other. In order that it may reach its maximum in the interval preceding the point having as its abscissa $a + \kappa\,\delta$, the load must be applied to this point and to all those which follow it, as far as the right abutment, the point in question being supposed on the left of the middle of the girder. We shall thus obtain for this maximum,

$$F = \frac{\delta}{2}(p + p')(N - 2\kappa + 1)\left[1 + \frac{\kappa(\kappa - 1)\delta^2 + a(2\kappa\delta - \delta + a)}{\delta(N\delta + 2a)(N - 2\kappa + 1)}q\right];$$

but this formula does not apply when $\kappa = 0$, that is for the extreme interval; in that case we have $F = \frac{1}{2}(p + p')(N\delta + a)$.

6. Usually all the intervals are equal to each other. Making, therefore, $a = 0$, and $l = N\delta$, we shall have $F = \frac{\delta}{2}(p+p')(N-2\kappa+1)\left[1+\frac{\kappa(\kappa-1)}{N(N-2\kappa+1)}q\right]$ in the interval included between the abscissæ $(\kappa-1)\delta$ and $\kappa\delta$. This formula holds good for the first interval.

To find the sum of the values of the transverse strain in all the intervals when N is an even number, take the sum of the preceding expression in which $\kappa$ assumes the successive values $1, 2, \frac{N}{2}$, and double the result for the whole bearing. We thus obtain

$$\Sigma F = (p+p')\frac{Nl}{4}\left(1+\frac{N^2-4}{6N^2}q\right)$$

and multiplying by $\delta$ we shall have the area of the polygon of the maximum straining forces absolutely considered. When N is an odd number, find the sum on the supposition that $\kappa$ varies from 1 to $\frac{N-1}{2}$, double the result, and add the force of the middle interval which will correspond with $\kappa = \frac{N+1}{2}$. We thus obtain $\Sigma F = (p+p')l\frac{N^2-1}{4N}\left(1+\frac{1}{6}q\right)$

The area of the polygon of the moments of rupture may be found by taking from the area of the circumscribed parabola N small segments, the chords of which have each $\delta$ as a horizontal projection, and the surfaces of which have the constant value $\frac{1}{12}(p+p')\delta^3$. We thus obtain for the area sought $(p+p')l^3\frac{N^2-1}{12N^2}$, a formula which applies whether N be an even or an odd number. We should have $\frac{1}{12}(p+p')(l^3-N\delta^3-2a^3)$ in the more general case in which $l = 2a + N\delta$.

7. When we have to consider an expression of the form $BF - AM$, where M denotes the moment of rupture with respect to the point the abscissa of which is $\kappa\delta$, and F the force in the interval preceding this point, we shall raise it to its maximum by applying the load to the point the abscissa of which is $\kappa\delta$ and to the following points of division as far as the right abutment, $\kappa\delta$ being supposed less than $\frac{l}{2}$. We obtain in this way the maxima value

$$\frac{p'\delta}{2N}(N-\kappa)(N-\kappa+1)(B-A\kappa\delta),$$

the term due to the permanent load not included. If, on the contrary, F were the force beyond the point the abscissa of which is $\kappa\delta$, to obtain the maximum we should have to suppress the weight at this point, and the formula would then be $\frac{p'\delta}{2N}(N-\kappa)(N-\kappa-1)(B-A\kappa\delta)$.

If the expression considered were of the form $BF - AM - A'M'$, M being the moment at the point the abscissa of which is $\kappa\delta$, M' that at the preceding point the abscissa of which is $(\kappa-1)\delta$, and F the force between these two points, this expression would be

$$\frac{p'\delta}{2N}(N-\kappa)(N-\kappa+1)[B-A\kappa\delta-A'(\kappa-1)\delta]$$

8. *Moments of Rupture produced by the Passage of a Wheel.*—A weight P applied to the point the abscissa of which is $a$, reckoning from the abutment, would produce moments of rupture represented by two right lines beginning at the supports and meeting at the loaded point where the ordinate reaches the value $\frac{Pa(l-a)}{l}$. But if this weight P be a wheel rolling from one end of the bearing to the other, the maximum moment at any given point will be produced when the wheel is passing over this point, and the maximum moments will be the parabola having the equation $M = \frac{Px(l-x)}{l}$ and the parameter $\frac{l}{P}$

If the girder support besides a uniform load P per lineal mètre, it will be sufficient to substitute for P in the preceding equation $P + \frac{pl}{2}$

But the parabola representing the moments due to P is only an imaginary one, since at any given instant there exists only one of its points, the one determined by the ordinate on the right of the load; and the moments of rupture at this instant are the broken line of which we have already spoken. The force F is also not derived from the parabola, but the inclination of one or the other of the right lines composing the broken line, according as we wish to find the force on one side or the other of the section considered.

9. *Moments of Rupture produced by Two Wheels.*—The two wheels occupying a determinate position, the moments of rupture are a broken line composed of three right lines. But to have at a given point the maximum moment we must bring one of the wheels of the vehicle upon it, the other wheel so placing itself that their common distance $d$ remains constant. If the left wheel P be placed upon the point the abscissa of which is $x$, the moment of rupture will be $M = \frac{x}{l}[Q(l-x) - P'd]$, Q representing the quantity $P + P' + \frac{pl}{2}$, on the hypothesis that the girder supports besides a permanent load $p$ a lineal mètre.

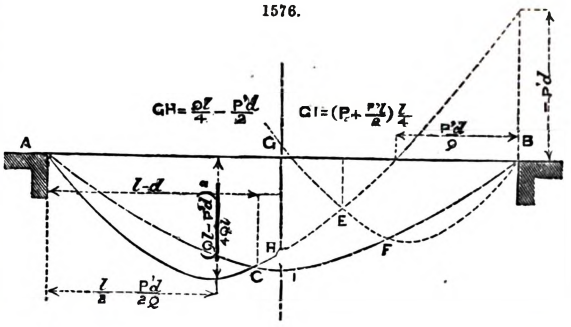
If P′ be brought upon the section in question, the wheel P removing to the left, we shall have

$$M' = \frac{x}{l}\,[Q\,(l-x) + P\,d] - P\,d.$$

The first equation will give a greater value than the second so long as $x$ is $< \frac{P\,l}{P+P'}$; beyond this limit we must take the second equation.

These two equations represent two parabolas A C E, B F E, Fig. 1576, of the same parameter $\frac{l}{Q}$, and having their axes vertical. But if the left wheel P be heavier than the right wheel P′, the parabola A C E produced by bringing the wheel P on the point the abscissa of which is $x$, will descend lower than the other. Now, when the vehicle returns in the opposite direction, we shall reproduce symmetrically the two parabolas, and then it will be the curve A C E and its symmetrical which will furnish the greatest ordinates, so that we shall have to lay aside the second equation.

1576.




We must observe again that the equation of the parabolas supposes both wheels always acting, even when one of them has passed beyond the support, in which case it will rest no longer upon the bearing, but upon the support. As the girder is supposed to terminate at the support when one of the wheels has passed beyond it, the curve is no longer applicable: we must in that case consider the parabola A C F B due to a single wheel towards the middle of the bearing. It is applicable only when the common distance $d$ of the wheels exceeds half the bearing; and supposing this condition fulfilled we obtain the various values numbered on the figure.

If with a certain section the girder offers an insufficient moment of resistance $\mu$ in the parts subject to the greatest strain, it will be necessary to strengthen the flanges throughout a length $\frac{1}{Q}\,(P'\,d + \sqrt{(Q\,l - p'\,d)^2 - 4\,Q\,l\,\mu})$, on the condition that this value be greater than $2\,d - l$.

In the contrary case, the theoretical length of the strengthening will be $\sqrt{\frac{P\,l^2 - 4\,l\,\mu}{P}}$.

10. When the two wheels of the vehicle are equal to each other the maximum moment occurs at the abscissa $\frac{2\,P\,(2\,l-d) + p\,l^2}{2\,(4\,P + p\,l)}$ and its value is $\frac{[2\,P\,(2\,l-d) + p\,l^2]^2}{8\,l\,(4\,P + p\,l)}$.

11. *Moments of Rupture due to Three Wheels.*—Let P, P′ P″ represent the weights of the three wheels moving from left to right, and $d$, $d'$ their common distances.

There are three geometrical figures of the moments of rupture to be considered during the passage of the vehicle, and each of these figures is composed of three parabolical arcs, the equations changing when one or two of the wheels pass beyond the bearing.

1. *Figure of the Moments obtained by bringing* P″ *upon the Variable Section considered.*

Making $P + P' + \frac{p\,l}{2} = Q$, $P' + P'' + \frac{p\,l}{2} = Q'$, and $P + P' + P'' + \frac{p\,l}{2} = Q''$.

From $x = 0$ to $x = d'$, P″ acts alone and gives $M = \frac{x}{l}\,(l-x)\left(P'' + \frac{p\,l}{2}\right)$;

From $x = d'$ to $x = d + d'$ we have $M = \frac{x}{l}\,\{\,Q'\,(l-x) + P'\,d'\,\} - P'\,d'$;

From $x = d + d'$ to $x = l$, $M = \frac{l-x}{l}\,\{\,Q''\,x - (P + P')\,d' - P\,d\,\}$.

2. *Figure of the Moments obtained by bringing* P′ *upon the Section.*

From $x = 0$ to $x = d$, we have $M = \frac{x}{l}\,\{\,Q'\,(l-x) - P''\,d'\,\}$;

From $x = d$ to $x = l - d'$, $M = \frac{x}{l}\,\{\,Q''\,(l-x) + P\,d - P''\,d'\,\} - P\,d$;

From $x = l - d'$ to $x = l$, $M = \frac{x}{l}\,\{\,Q\,(l-x) + P\,d\,\} - P\,d$.

3. *Figure of the Moments obtained by bringing* P *upon the Section.*

From $x = 0$ to $x = l - d - d'$, $M = \frac{x}{l}\,\{\,Q''\,(l-x) - (P' + P'')\,d - P''\,d'\,\}$;

From $x = l - d - d'$ to $x = l - d$, $M = \frac{x}{l}\,\{\,Q\,(l-x) - P'\,d\,\}$;

From $x = l - d$ to $x = l$, $M = \frac{x}{l}\,(l-x)\left(P + \frac{p\,l}{2}\right)$.

The parameter of each parabola is the reciprocal quantity of the mean load per lineal mètre, reckoning only the half of the uniformly distributed load $p$.

Having constructed these three geometrical figures, we have to consider each of them only in that portion in which it gives ordinates greater than the others; and as the vehicle may be brought back in the other direction, we can reproduce symmetrically the maxima curves, which will always eliminate, if not already eliminated, the cases of a single wheel expressed by the first and last of the nine equations given above.

12. The following particular case deserves notice. If the vehicle be turned so that

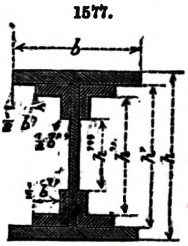
$$P > P'' + P' \frac{d - d'}{d + d'},$$

it will be sufficient to consider the first half of the girder. Again, if $l - d - d'$ exceeds each of the quantities $d$, $d'$, and $\frac{P(d+d)}{P' + P''}$, we must consider only the seventh and fifth of the nine equations, the seventh between the abscissæ O and $\frac{P\,l}{P + P' + P''}$, and the fifth between the latter abscissa and the middle of the girder. A girder, the simple section of which has a moment of resistance $\mu$ inferior to the maximum moment of rupture, should be strengthened throughout a length expressed by $\frac{P''(d+d') + P'\,d}{Q''} + \frac{1}{Q''}\sqrt{\{Q''\,l - P''(d+d') - P'\,d\}^2 - 4\,Q\,l\,\mu}$, on the condition that this length exceed $\frac{P' + P'' - P}{P + P' + P''}\,l$. In the contrary case the theoretical length of the strengthened part should be $\frac{P\,d - P''\,d'}{Q''} + \frac{1}{Q''}\sqrt{(Q''\,l + P\,d - P''\,d')^2 - 4\,Q''\,l\,(\mu + P\,d)}$. The value of the maximum moment is $\frac{1}{4}\left\{Q''\,l - 2\,P\,d - 2\,P''\,d' + \frac{(P\,d - P''\,d')^2}{Q''\,l}\right\}$.

For example, if $l = 6$ mètres, $P = P' = P'' = 6000$ kilogrammes, $p = 0$, $d = 1{\cdot}40$ mètre, $d' = 1{\cdot}90$ mètre, the maximum moment will be 17120, equal to that which would be given by a uniformly distributed load of 3800 kilogrammes the lineal mètre.

13. *Moments of Resistance of Solid Girders.—Girders with Equal Flanges.*—For girders of inconsiderable height, the moment of resistance is calculated by the exact formula $\frac{R}{6\,h}(b\,h^3 - b'\,h'^3 - b''\,h''^3 - b'''\,h'''^3)$, Fig. 1577.

1577.




Tables I. and II. give the moments ready calculated of various sections. Part of these results has been taken from more extensive Tables published by M. Foy in the 'Annales de la Construction' of M. Opperman, 1863. As usual, the value of R has been taken as 6000000; but if it be required to give to R another value, it will be easy to modify these results by a simple proportion.

When a section according to the Table would be too weak or too strong for the girder proposed, we can modify the thickness of the flanges or of the vertical rib, remembering always that every millimètre added to or taken from the latter increases or diminishes the moment of a quantity $= 1000\,h^2$; and that every millimètre in each of the two flanges causes an alteration of $6000\,b\,h$.

14. When the girder is not a very low one, the moment of resistance may be rapidly calculated by an approximative formula. With the dimensions denoted in Fig. 1577, the moment of resistance of the horizontal flanges, abstracting the rib and angle-irons, is exactly $R\,b\,\frac{h^3 - h'^3}{6\,h} = M$; but if we take $M' = R\,b\,h'.\,\frac{h - h'}{2} = R\,s\,h'$, $s$ being the section of one of the horizontal flanges, we shall have $\frac{M'}{M} = \frac{3\,h\,h'(h - h')}{h^3 - h'^3}$.

For example, if $h'$ is at least $0{\cdot}8$ of $h$, and this is always the case when the girder is of inconsiderable height, the proportion $\frac{M'}{M}$ will be equal to $0{\cdot}983$, which is very near unity.

As $h'$ differs little from $h$, we may consider the moment of resistance of the vertical rib of thickness $e$ as equal to $R\,e\,\frac{h'^2}{6}$ or $\frac{1}{6}\,R\,s'\,h'$, $s$ being the section $e\,h'$. Thus the vertical rib gives a moment of resistance equal to only $\frac{1}{3}$ of that which the same quantity of material would possess if equally distributed between the two horizontal flanges.

For the angle-irons, if we limit ourselves to $\frac{80/80}{10}$ and $\frac{100/100}{12}$, we can make use of Table III., which gives the moments of resistance ready calculated of four angle-irons (two at the top and two at the bottom), supposing that R reaches the value 6000000 in the fibres situated at the extremities of the height $h'$. If we get beyond these limits, we can reduce the values of the Table. Thus for angle-irons of $\frac{100/100}{15}$ we must add $\frac{1}{4}$ of the value given by the Table for angle-irons of $\frac{100/100}{12}$. When the height is inconsiderable, instead of considering the angle-irons apart, we may include them in the section $s$ of the flange.

Let us take, by way of example, a girder 0·80 mètre in height, consisting of a vertical rib of 700/12 millimètres, four angle-irons of $\frac{80/80}{10}$, and two flanges of 300/50. We shall have $h' = 0{\cdot}70$, $s + \frac{1}{6}s' = 0{\cdot}0164$, and consequently

| | |
|---|---|
| The moment of resistance of the rib and flanges = 6000000 × 0·0164 × 0·70 = | 68880 |
| The moment of resistance of the angle-irons, according to Table III. .. .. | 11014 |
| Total .. .. .. .. .. .. .. .. .. | 79894 |

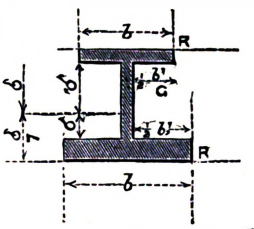
The exact calculation gives 78158. Supposing the moment of rupture to be equal to 79894, the girder would have to bear a strain of 6·13 kilogrammes instead of 6, a difference which is of no importance.

15. *Moments of Resistance of Unequal Sections with respect to the so-called Neutral Axis.*—The strain which iron is usually reckoned to bear is 6 kilogrammes the square millimètre, both in those parts which are subject to compression and in those which are subject to tension, the compressed parts requiring only a proper form to prevent twisting. But if it be required to employ a higher coefficient for the flange subject to tension than for the one subject to compression, we must increase the strength of the latter, that is, we must adopt an unequal section with respect to the neutral axis.

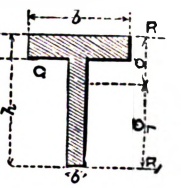
These unequal sections may be unavoidable in certain cases; for example, in girders of the form given in Fig. 1588. In such a case, it is often possible to assimilate the section to an equal one having the two flanges equal to the weakest of the given section. But if the exact calculation be required, we must proceed as follows:—

First find, by the theorem of moments, Fig. 1578, the sides of a height $\delta$ and $\delta'$ which fix the position of the centre of gravity G of the section, which coincides with the neutral axis when the girder is only subject to forces normal to its length. Then, between the coefficients R and $R_1$, which express respectively the maximum resistance of the two flanges, we shall have the proportion $\frac{R}{R_1} = \frac{\delta}{\delta'}$. The moment of resistance may be expressed either in terms of R or of $R_1$ which are connected by the preceding proportion; in terms of R, for example, Fig. 1579, its value will be $\frac{R}{3\delta}(b\,\delta^3 + b_1\,\delta_1^3 - b'\,\delta'^3 - b_1'\,\delta_1'^3)$.

1578.



1579.



In the particular case of a simple ⊤, Fig. 1579, we shall have $\delta = \frac{1}{2} \cdot \frac{b\,h'^2 - b'\,h'^2 + b'\,h^2}{b\,h' - b'\,h' + b'\,h}$. Moment of inertia $I = \frac{1}{3}\left\{b\,\delta^3 - (b - b')\,(\delta - h')^3 + b'\,(h - \delta)^3\right\}$. Moment of resistance $= \frac{R_1 I}{h - \delta}$, $R_1$ referring to the fibre which is farthest from the neutral axis.

16. *Solid Girders of small dimensions.—Coefficient R.—Rivetings.*—Theoretically the thickness of the vertical rib should vary with the strain to which it is to be subject; but in small girders this thickness is fixed, and offers an excess of resistance, for the conditions of rigidity prohibit the reduction of the thickness of the iron plates below certain limits. We may, therefore, consider the thickness $e$ of the rib as given.

If we first suppose the section constant, and represented in detail by Figs. 1580 to 1585, the value of the moment of resistance will be

$$M = \frac{R}{6h}\left\{b\,h^3 - (b - e)\,(h - 2\epsilon)^3\right\} = R\,\epsilon\,(b - e)\left(h - 2\epsilon + \frac{4\epsilon^2}{3h}\right) + \frac{R\,e\,h^2}{6}.$$

We may neglect, relatively to $h$, the term $\frac{4\epsilon^2}{3h}$, and take

$$M = R\left\{\epsilon\,(b - e)\,(h - 2\epsilon) + \frac{e\,h^2}{6}\right\}; \qquad [1]$$

whence $b = \frac{M}{R\,\epsilon\,(h - 2\epsilon)} + e - \frac{e\,h^2}{6\epsilon\,(h - 2\epsilon)}$.

The area of the section, or the volume of the lineal mètre of girder, is expressed by

$$2\,b\,\epsilon + (h - 2\epsilon)\,(e + \psi);$$

$\psi$ representing the volume of the joint-plates and mouldings of the rib the square mètre, that is, the additional thickness which must be given to the rib to equal the weight of these mouldings and joint-plates.

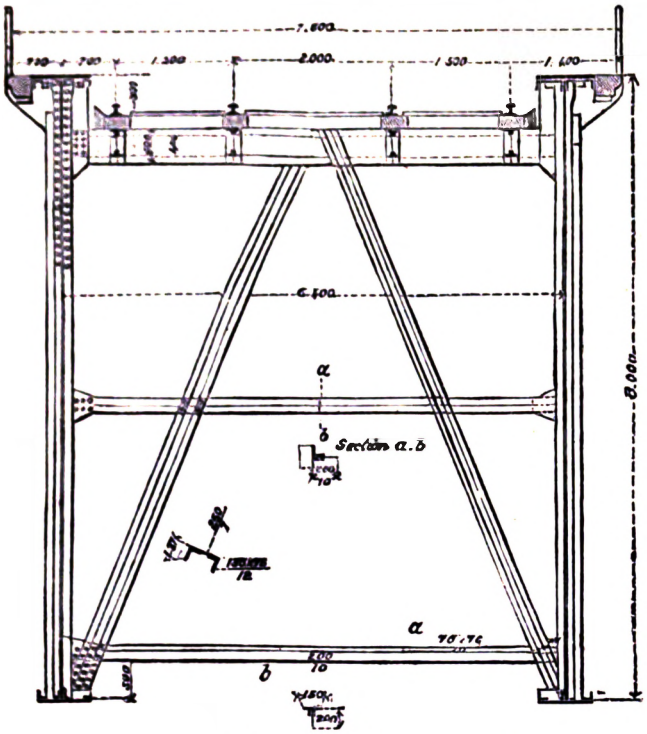
Substituting this value for $b$, the expression becomes $\frac{6M + 2R\,e\,h^2 - 6R\,e\,\epsilon\,h}{3R\,(h - 2\epsilon)} + \psi\,(h - 2\epsilon)$, and it is reduced to a minimum by the following value of $h$:

$$h = 2\epsilon + 2\sqrt{\frac{3M - 2R\,e\,\epsilon^2}{2R\,(2e + 3\psi)}} \qquad [2]$$

This formula gives the height to be adopted in order to have the lightest possible girder, offering a given moment of resistance, the quantities $e$, $\psi$ and $\epsilon$ being also given.

1580.

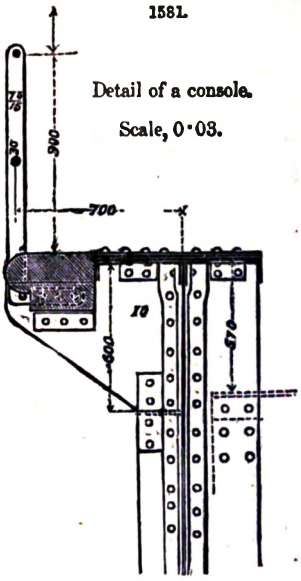
*Two-girder Bridge, of high girders, loaded on the upper part.*




1581.

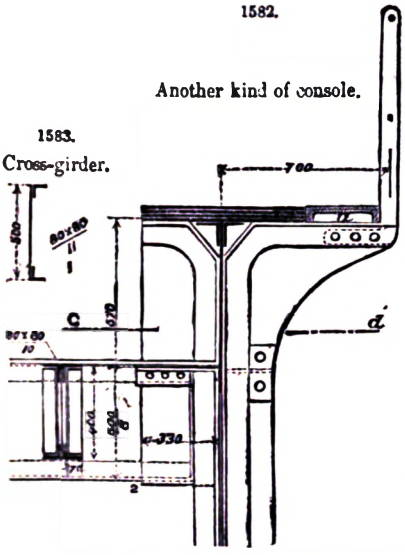
Detail of a console.

Scale, 0·03.




1582.

Another kind of console.

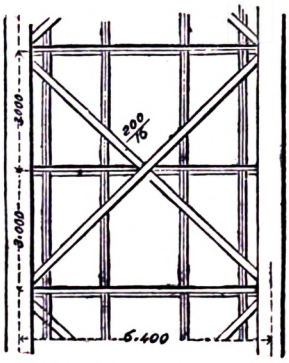



1583.

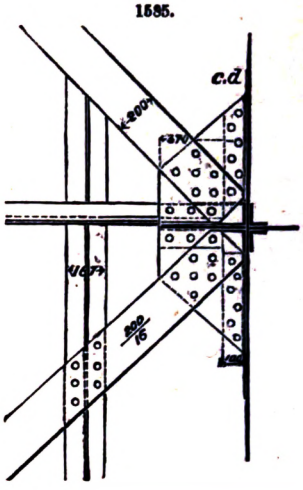
Cross-girder.

1584.

Truss-bars on the upper side.




1585.




Eliminating M between [1] and [2], and supposing $e = \epsilon$, we obtain

$$h = \frac{6e(b+\psi)}{e+\psi}. \qquad [3]$$

a formula which establishes between $h$ and $b$ the most advantageous relation, $e$ being always given, and, in the interests of economy, requiring to be chosen as small as the necessary rigidity will allow. In girders of rolled iron $\psi = 0$, and, consequently, $h = 6b$; thus, for this kind of girder, if we choose the area S of the section, the best form will be obtained by adopting for $e$ the smallest possible value, and then taking $h = \frac{3S}{4e}$ and $b = \frac{S}{8e}$

Formula [2] assumes the following form in the case of a girder supporting a uniformly distributed load $p$ per lineal mètre of bearing $l$.

$$h = 2\epsilon + \frac{1}{2}\sqrt{\frac{3pl^2 - 16Re\epsilon^2}{R(2e+3\psi)}}. \qquad [4]$$

17. Let us now consider the case of girders having flanges of varying thickness. As the increase of thickness is obtained by placing one plate upon another, the variation takes place by redans or gradations, from the middle to the extremities of the bearing. If $\mu$ denote the moment of resistance of one of the sections, the additional material to be added in the middle will, theoretically, be equal in length to $\sqrt{l^2 - \frac{8\mu}{p}}$, supposing the girder loaded with $p$ the lineal mètre. This length should, in practice, be slightly increased, in order that the added plate may form sufficient consistency with the flange by means of its extreme rivets, at those points in which the strengthening becomes necessary.

Let us suppose that Figs. 1580 to 1585 represent the section at the ends of the girder, $\epsilon$ being the least thickness it is thought proper to adopt for the flanges; then, admitting approximatively that from the extremities this thickness increases as the ordinate of a parabolical segment, so as to reach its greatest value $z$ in the middle of the bearing, the thickness $z$ will be determined by the following equation, in which the moment of resistance is expressed in the approximative manner explained in 14.

$$\mathrm{R}\,h\left(b\,z + \frac{e\,h}{6}\right) = \frac{p\,l^2}{8}, \text{ whence } b\,z = \frac{p\,l^2}{8\,\mathrm{R}\,h} - \frac{e\,h}{6}. \qquad [5]$$

Let $\kappa$ be a coefficient 1·10 taking into account the joint-plates of the flanges. The volume of the lineal mètre of girder will then be $l\,h\,(e+\psi) + 2\,\kappa\,l\,b\left\{\epsilon + \frac{2}{3}(z-e)\right\}$; or, by substituting the value of $b\,z$, $l\,h\left\{\psi + e\,(1-\frac{2}{9}\kappa)\right\} + \frac{2}{3}\kappa\,l\,b\,\epsilon + \frac{\kappa\,p\,l^3}{6\,\mathrm{R}\,h}$.

This expression becomes a minimum if we take

$$h = l\sqrt{\frac{\kappa\,p}{6\,\mathrm{R}\left\{\psi + e\,(1-\frac{2}{9}\kappa)\right\}}}, \qquad [6]$$

which shows that the height of girders should vary as $l\sqrt{p}$.

The height being determined, the middle section of the flanges is calculated by equation [5]. The breadth $b$ must be sufficient to ensure the rigidity of the girder, and to prevent the thickness $z$ from exceeding a certain limit, such as 0·06 or 0·07 mètre.

*Examples.* — Let $l = 20$ mètres, $p = 6000$ kilogrammes, $e = 0{\cdot}010$ mètre, $\psi = 0{\cdot}008$, R = 6000000, and $\kappa = 1{\cdot}10$. We find $h = 2{\cdot}17$ mètres, and $p\,z = 0{\cdot}0194$. If, for example, we make $z = 0{\cdot}050$, we shall have $b = 0{\cdot}39$ mètre. Supposing $\epsilon = 0{\cdot}010$, the girder will weigh about 11 tons, or 22231 lbs.

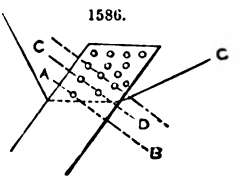
The above formulæ apply only to cases in which we are free to realize the most advantageous forms. It frequently happens that the height allowed is limited, in which cases we must adapt the height of the girder to the circumstances imposed upon us. The thickness of the vertical rib varies in girders of great importance.

18. *Coefficient R.*—The practical resistance of iron both to tension and to compression is usually taken as 6 kilogrammes to the square millimètre, and this coefficient is regarded as applicable to the solid section, that is, without any deduction for rivet-holes. In the parts subject to compression, these holes do not weaken the piece in the slightest degree, if they are exactly filled by the shank of the rivets; but this condition is not always fulfilled. In the parts subject to tension the hold which the heads of the rivets have taken upon the plate in consequence of the shrinking of the metal, partly compensates the loss of strength occasioned by the hole; but we must always reckon upon a loss in virtue of which R will exceed 6 kilogrammes.

When certain points, such as the situation of joint-plates, for example, require a greater degree of perforation than the other parts, it will always be advisable to slightly increase the section in these points.

In the case of bars fixed to gussets by several rows of rivets, the loss may in most cases be rendered trifling by a proper arrangement of the holes: for example, one rivet only may be put in the transverse section A B, Fig. 1586, two in C D, three in the following row, and so on; for it is enough if, in any section, the net resistance retained equals the strain upon the bar diminished by the resistance of the rivets which precede the row under consideration. Or, instead of this, we may vary only the diameter of the rivets which should increase towards the end of the piece. Or, again, the two methods may be combined. In lattice-girders, in which every bar is of inconsiderable section, a single hole, even when it is of small size, may be an important fraction of the section, in which case it will be advisable to increase the section, at least in the bars subject to tension; in those subject to compression it is often necessary to enlarge the dimensions for the sake of rigidity, and this excess of section, needed in the middle to prevent deflection, is serviceable at the extremities in compensating the loss occasioned by the rivets.

1586.




Thus in certain cases it is necessary to take into account the weakening of the material by rivet-holes, but, generally, we may consider that the coefficient R = 6000000 is sufficiently low to permit us to neglect it.

19. *Rivetings and Bolts.*—The resistance of these to *shearing force* might be considered equal to their resistance to tension or compression, when it is effected under favourable circumstances. But as the joints often require a greater number of rivets, they will not resist in an equal degree. For

this reason it is usual to reckon their resistance at 4 kilogrammes the square millimètre. In accordance with this, a rivet of $0^m \cdot 022$ in diameter, offering a single section, should support 1½ ton, or 3031 lbs.; and one of $0^m \cdot 25$, 2 tons, or 4042 lbs. The distance of the holes apart may be about $0^m \cdot 08$.

When a small surface only of a bar rests upon its gusset, it is often necessary to double the sections of the rivets to enable them to resist the shearing strain; this is effected by placing a joint-plate on the opposite side of the gusset, extending an equal distance along the bar. The space between the bar and the joint-plate is then filled up, so that the gusset is fixed into a kind of fork, which can be torn away only by shearing the rivets through two sections. In certain cases, it will be easier and less expensive to enlarge the gusset and retain only a single section of bolt. By doubling the gussets and joint-plates, the rivets will offer a quadruple section. The thickness of the gussets should be so calculated that there may be no risk of their giving way along the perimeter enveloping the rivets of the bar.

We may observe, with respect to the joint-plates of the flanges, that it will be prudent to place considerably apart the holes of those transverse rows which are nearest to the joint and to the ends of the joint-plate, and, on the contrary, to place them closer together in the intermediate rows. This condition may be disregarded with respect to the rows nearest the joint, if we increase the thickness of the joint-plate. But even then it is as well to increase the length, and to place the rivets farther apart.

The vertical rib of a malleable iron girder has a tendency to slide between the two angle-irons which fix it to each of the horizontal flanges. We saw in I that this horizontal shearing strain requires a thickness of rib $e$ given by the equation $\frac{d\mathrm{M}}{h} = \mathrm{R}, e\,dx$. Taking account of the rivets, we shall have $\frac{d\mathrm{M}}{h} = n\,\mathrm{Q}\,dx$, $n$ being the number of rivets the lineal mètre, and Q the strain borne by one of them upon a double section. Whence we deduce $n = \frac{1}{\mathrm{Q}h} \cdot \frac{d\mathrm{M}}{dx} = \frac{\mathrm{F}}{\mathrm{Q}h}$.

Supposing $p\kappa$ the lineal mètre of girder, the maximum of strain F will be $\frac{pl}{2}$, and by using rivets of $0^m \cdot 025$ we shall have Q = 4000 kilogrammes; consequently $n = \frac{pl}{8000\,h}$, that is, at the extremities of the girder, the rivets fixing the rib to the angle-irons of the flanges should be placed apart the distance of $\frac{1}{n} = \frac{8000\,h}{pl}$. With a diameter of $0^m \cdot 022$ the distance should be $\frac{6000\,h}{pl}$.

The same considerations apply to the rivets which hold together the plates of the flanges, or which fix them to the horizontal arm of the angle-irons, but in these cases the distance may be increased on account of the relatively less sliding strain.

The foregoing condition will, in general, allow us to place the rivetings wide apart throughout the greater part of the length of the flanges; but in the flange subject to compression the rivetings serve another purpose, which must be borne in mind; namely, that of preventing the exfoliation of the plates, which would inevitably occur if they were insufficiently fixed together. This condition requires that the plates should not be left free throughout a length exceeding $0^m \cdot 15$; but when there are several rows of rivets, the distance may in certain cases be doubled, provided we take care to alternate the holes.

The holes should be placed closer together in a line with the joint, in order to avoid uselessly increasing the length of the joint-plates.

When the number of plates of which the flange is composed is grea., the joints are near together; and in this case the rivetings should extend, at small intervals, throughout the whole of the length.

20. *Flooring of Bridges.—Parts beside the chief Girders.*—When the rails do not rest directly upon the principal girders, these are made to support cross-girders, upon which again are placed, longitudinally, other and lesser girders, and it is upon these latter that the rails are laid.

We may consider these minor supports as simply resting upon the cross-girders, and we may take as their bearing the distance of these latter from each other. If the rolling load consists of the wheels of a locomotive, the weight of which is 7 tons, and their distance apart $1^m \cdot 40$, one of the wheels in the middle of the girder will give the maximum moment, when the bearing is less than $2^m \cdot 40$. Above this it will be necessary to consider two wheels. The dead weight, which is of small importance relatively to the rolling load, may be reckoned at the rate of 500 kilogrammes the lineal mètre. With these hypotheses, we can adopt, according to the various lengths of bearing and the height to be given to the girder, the double T sections of Table IV., in which $l$ denotes the bearing, M the maximum moment of rupture, and $h$ the height of the girder. As we have done in the Table of the moments of resistance, so in this we describe a section by indicating, first the dimensions of the vertical rib, then those of one of the four angle-irons, and last, when there is occasion for it, those of one of the flanges; for these latter, we give also the length, which in secondary girders of more than 3 mètres may be considerably less than the bearing, for these horizontal plates must be regarded as simple additions made for strength. When the length is omitted, it is understood to be equal to that of the angle-irons. The letter P denotes the mean weight of the girder a lineal mètre, having taken into account the reduction in the length of the strengthening portions, and the cutting away of the angle-irons at the ends of the girder, where the vertical rib alone is retained to be fixed to vertical flanges in the cross-girder. These vertical flanges are not reckoned here, because we consider them as forming a part of the cross-girder.

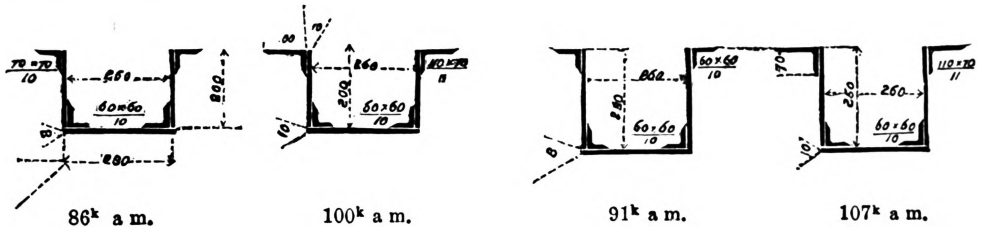
In sections consisting only of a rib and angle-iron, the latter should offer a broad surface to the balks of timber carrying the rails; it will sometimes be advisable to substitute unequal-armed angle-iron for equal-armed, care being had to preserve nearly the same weight: the resistance will be increased by the change, but if this condition is already amply satisfied, we need alter only the top angle-irons. In a bridge hereafter described, we have secondary girders reaching a length of bearing equal to 6 mètres. The mean weight of each of these is about 110 kilogrammes the lineal mètre.

21. When the height allowed is very limited, hollow girders in the form of caissons are sometimes used. This form is less economical than that of the double T, but it is favourable to the reduction of the thickness of the flooring without diminishing the necessary thickness of the timbers. Figs. 1591, 1594, 1595, give an example of this arrangement. Other sections suitable for bearings of $1^{m} \cdot 50$ to $2^{m} \cdot 50$ are found in Figs. 1587 to 1590. It is useless to consider longer bearings than these, for when the height is very limited the cross-girders should not be placed far apart.

1587. 1588. 1589. 1590.

*Hollow Minor Girders.* Scale, 0·05.

For a bearing of $1^{m} \cdot 50$. For a bearing of $2^{m} \cdot 00$. For a bearing of $2^{m} \cdot 500$.



$86^{k}$ a m. $100^{k}$ a m. $91^{k}$ a m. $107^{k}$ a m.

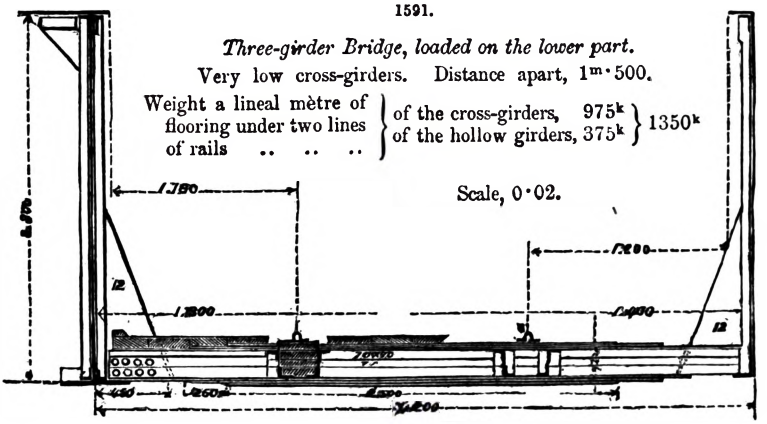
1591.

*Three-girder Bridge, loaded on the lower part.*

Very low cross-girders. Distance apart, $1^{m} \cdot 500$.

Weight a lineal mètre of flooring under two lines of rails .. .. .. } of the cross-girders, $975^{k}$ of the hollow girders, $375^{k}$ } $1350^{k}$

Scale, 0·02.



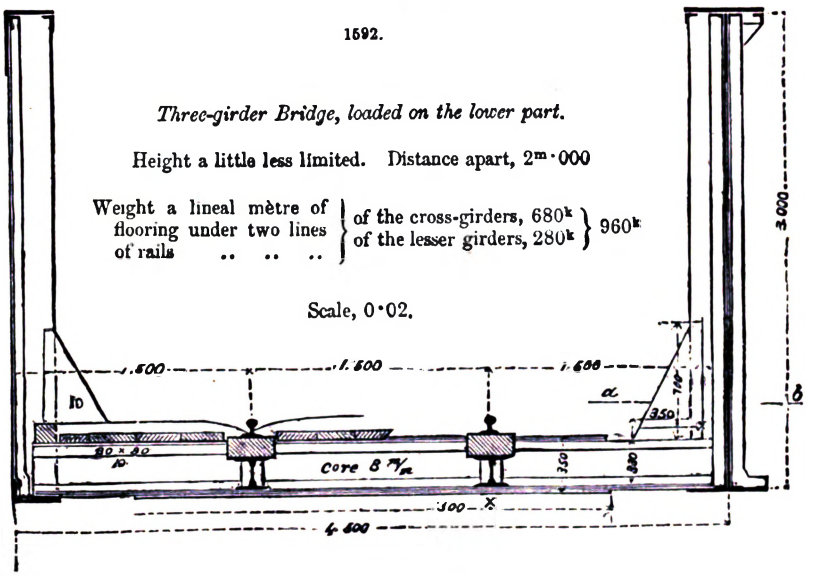
1592.

*Three-girder Bridge, loaded on the lower part.*

Height a little less limited. Distance apart, $2^{m} \cdot 000$

Weight a lineal mètre of flooring under two lines of rails .. .. .. } of the cross-girders, $680^{k}$ of the lesser girders, $280^{k}$ } $960^{k}$

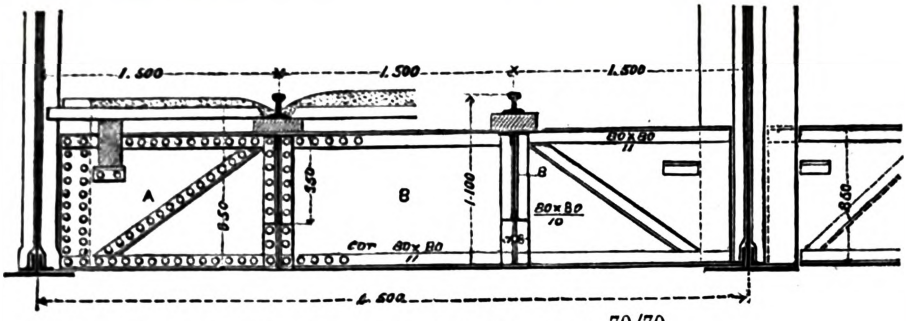
Scale, 0·02.



1593.

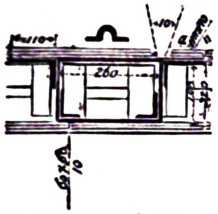
*High Cross-girders.* Distance apart, $4^{m}\cdot00$.

Weight a lineal mètre of flooring under two lines of rails .. .. .. .. .. .. { of the cross-girders, $310^{k}$ / of the minor girders, $320^{k}$ } $630^{k}$

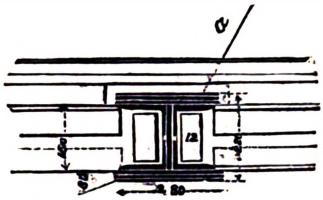



A, angle-iron on one side only to stiffen the rib $\frac{70/70}{10}$.

1594. *Details, to a scale of* 0·05. 1595.

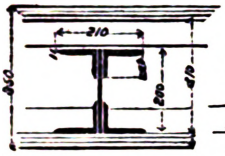



Hollow girder of $93^{k}$ the mètre.

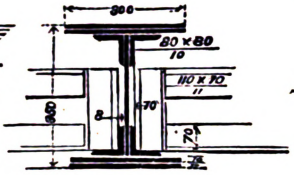


Length of the 1st plate of the flanges, $3^{m}\cdot40$.
„ 2nd „ „ $3^{m}\cdot00$.
„ 3rd „ „ $2^{m}\cdot50$.

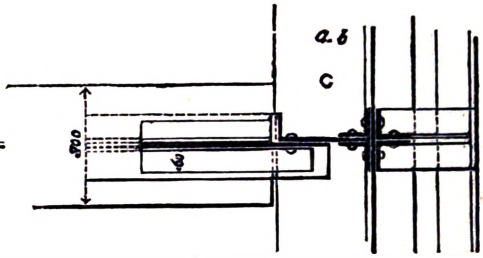
1596. Minor girder.




1597. Cross-girder.




1598.




When the thickness will allow us to give a height of, at least, $0^{m}\cdot350$ to the cross-girders, we may adopt the double T form for the longitudinal girders.

22. *Cross-girders for Bridges of Three Girders.*—Figs. 1591 to 1598 represent various kinds. When the height allowed is very limited, the distance of the cross-girders apart should be reduced to about $1^{m}\cdot50$. It will be useless to go lower than this, for we should still have to consider the cross-girder as loaded, in a line with each rail, with one wheel of the locomotive. In these cases, the principal girders should be placed as near together as possible, in order to diminish the bearing of the cross-girders. Taking their distance apart equal to $4^{m}\cdot20$, as in Figs. 1591, 1594, 1595, the length of the cross-girder will be 4 mètres, its actual bearing being, in consequence of the projecting of the gussets, $3^{m}\cdot60$. Under these circumstances, the height of the cross-girder may be reduced to $0^{m}\cdot220$, as in the figure; its weight is about 730 kilogrammes, including its two gussets; the cross-girders, therefore, will weigh 975 kilogrammes the lineal mètre of flooring under two lines of rails.

For a height of $0^{m}$ 250, we may take a rib of 210/10 millimètres, angle-irons of 110/70/11, and flanges of 270/20 composed of two plates, one extending over a length of $3^{m}\cdot50$, and the other over $2^{m}\cdot70$ only. The weight of the cross-girders will be reduced to 830 kilos.

It will be brought down to 715 kilos., if we can take a section of $0^{m}\cdot300$ in height, composed of a rib of 260/12, angle-irons of 70/70/10, and flanges of 220/20, the first plate of which should extend $3^{m}\cdot50$ and the other $2^{m}\cdot70$.

Again, this same weight will be reduced to 640 kilos. for cross-girders of $0^{m}\cdot350$, the rib being 330/10, the angle-irons 80/80/10, and the flanges 250/10 throughout a length of 3 mètres.

23. But generally we shall follow the example given in Figs. 1592, and 1596 to 1598, in which the chief girders are placed at a distance of $4^{m}\cdot50$ apart. In this case the space between the two lines of rails, known as the "six-feet way," is increased to 3 mètres at each end of the bridge, in

order to keep clear of the middle girder. The length of the cross-girders is $4^m \cdot 30$, and they may be regarded as simply resting upon two supports, the actual bearing being about $4^m \cdot 10$. The rolling load acts in two distinct points, in a line with each rail, and we may suppose the dead weight to act in the same manner. The moment of rupture will be equal to $1 \cdot 30$ P, the letter P denoting the maximum total weight acting in a line with each rail. This weight increases with the distance between the cross-girders; and if we consider the case of locomotives carrying 10 tons per axle, with a distance of $1^m \cdot 10$ between the axles, or carrying 12 tons, with a distance of $1^m \cdot 40$ and $1^m \cdot 90$, we may allow the following values of P:—

| Distance apart of cross-girders | Mètres. 1·50 | Mètres. 2·00 | Mètres. 2·50 | Mètres. 3·00 | Mètres. 3·50 | Mètres. 4·00 | Mètres. 4·50 | Mètres. 5·00 |
|---|---|---|---|---|---|---|---|---|
| Portion of P due to the dead weight .. .. .. .. .. | Kilos. 1700 | Kilos. 2000 | Kilos. 2100 | Kilos. 2300 | Kilos. 2500 | Kilos. 2800 | Kilos. 3100 | Kilos. 3500 |
| Portion of P due to the rolling load .. .. .. .. .. | 7600 | 9500 | 10600 | 11400 | 12300 | 13000 | 13600 | 14000 |
| Total value of P .. .. .. | 9300 | 11500 | 12700 | 13700 | 14800 | 15800 | 16700 | 17500 |

We are thus able to form a Table (see Table V.) in which M denotes the maximum moment of rupture. The weights include the vertical flanges by means of which the lesser girders are fixed to the cross-girders, and the triangular gussets by means of which the latter are fixed to the principal girders. On the other hand we have deducted the portions of angle-iron or horizontal plates, which are removed towards the ends of the cross-girders.

24. *Cross-girders for Two-girder Bridges.*—Exemplars of these are given in Figs. 1599 to 1604. The total length of the cross-girder is supposed equal to 8 mètres, and we may admit $7^m \cdot 80$ as the actual bearing. The maximum moment of rupture, between the inner rails, will be 4·30 P, when the two lines are simultaneously loaded, whilst it will be only 2·70 P in the case of one line being loaded. We may reckon the mean 3·50 P as equal to the moment of resistance R = 6000000. By this means we shall obtain cross-girders supporting generally a strain of 4·5 kilos. the square millimètre, omitting the exceptional case of both lines being loaded simultaneously, when the strain may rise to 7·5 kilos. In a line with the exterior rails, the mean moment will be 2·40 P.

1599.

*Two-girder Bridge, loaded on the lower side.*

Cross-girders of $0^m \cdot 60$ in height, and $2^m$ apart.

Weight of the cross-girder with gusset A, $1740^k$.

Weight a lineal mètre of flooring .. .. { of the cross-girders, $870^k$ / of the minor girders, $180^k$ } $1050^k$

Scale, 0·02.

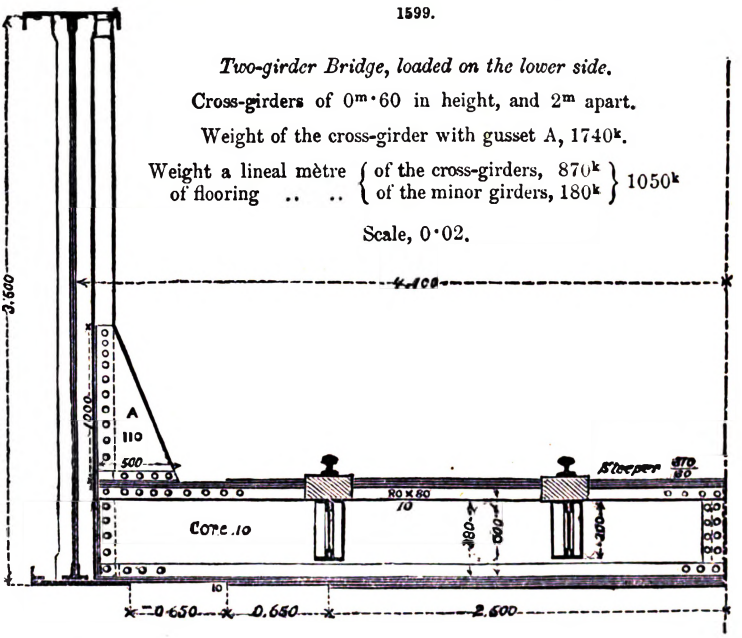



Table VI. gives a certain number of sections for various distances. The weights include all accessories.

25. *Vertical Trussing.*—When the girders of a bridge are very high and their flanges comparatively narrow, they are liable to incline or sag from one side to the other, especially if they are loaded on the upper part. If the direction of the sagging is different at the two ends of the girder, a strain of torsion is produced, which changes the plane of the vertical rib into an oblique surface. The principal object of vertical trussing is to counteract these effects of sagging. The strain borne by these pieces is caused by the motion of the trains, which produces lateral oscillations, or by the deflections which occur in the flange subject to compression. But it is often needful to strengthen the oblique pieces of the transverse section, because they may serve as supports to the cross-girders, of which arrangement Figs. 1605 to 1611 and Figs. 1580 to 1585 are examples.

The object of vertical trussing cannot be to equalize the deflections of the several girders in cases when these girders may be unequally loaded, for in such cases the deflections must of necessity differ: it could be prevented in part only by means of very strong pieces, and there would then result a strain of torsion. Yet, when the girders are high and rigid, the deflections are so inconsiderable that the vertical trussing does offer some resistance, because, by its elasticity, it adapts itself sufficiently to the different curves which the girders assume under the rolling load. Between two girders equally loaded, such as two girders supporting directly the

rails of one line, these strains do not exist. In four-girder bridges under rails, if the height be inconsiderable, it will be sufficient to simply tie the two lines.

26. *Horizontal Trussing.* — One use of horizontal trussing is to prevent lateral vibration, and in order to effect this in the most complete manner the trussing should be placed as near the plane of the rails as possible. Another use of this kind of trussing is to form, with the aid of the cross-girders, a resisting plane which shall prevent the girder from twisting under the torsive strain of the compressed flange. From this point of view the trussing should, when possible, bind together the compressed flanges of the several girders. When the bridge is loaded on the upper part, a top trussing will satisfy the double condition. In tubular bridges loaded on the lower part, an upper and a lower trussing will be necessary. And in bridges of girders loaded on the lower side, a top trussing being impossible, we can have only a lower one, but care should be had to prevent the twisting of the girders by widening their top flanges and the upright stays which serve to stiffen them.

The trussings or bracings act in the same way as horizontal lattice-bars, but the strains to which they are subject are of a capricious nature that eludes calculation. They are usually formed of bars of a uniform dimension throughout the whole length of flooring; but in important works it may be advisable to strengthen the bars near the supports, especially if the line be curved upon

1600.

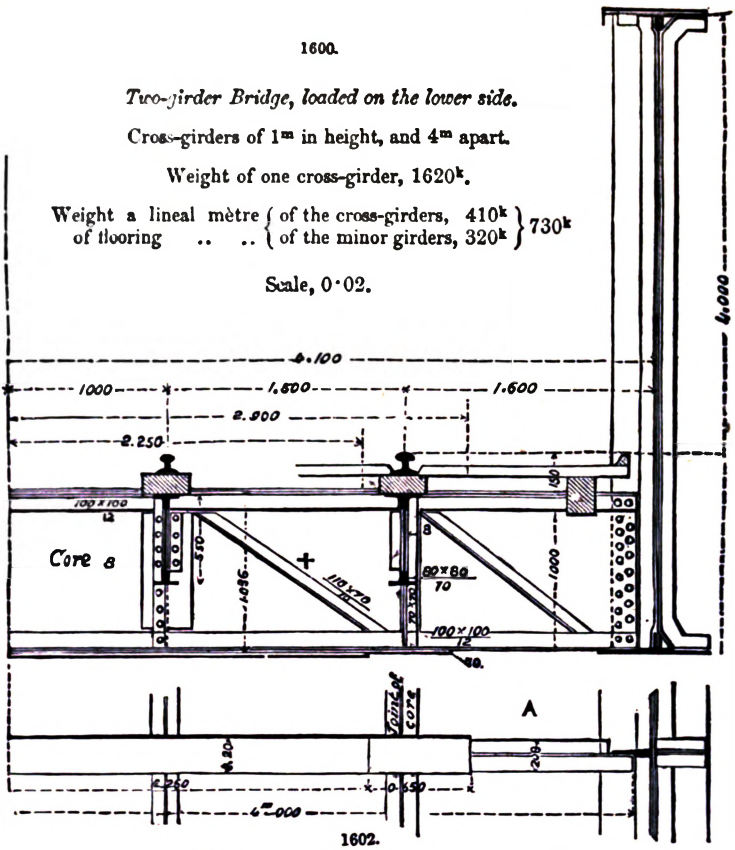
*Two-girder Bridge, loaded on the lower side.*

Cross-girders of 1$^{m}$ in height, and 4$^{m}$ apart.

Weight of one cross-girder, 1620$^{k}$.

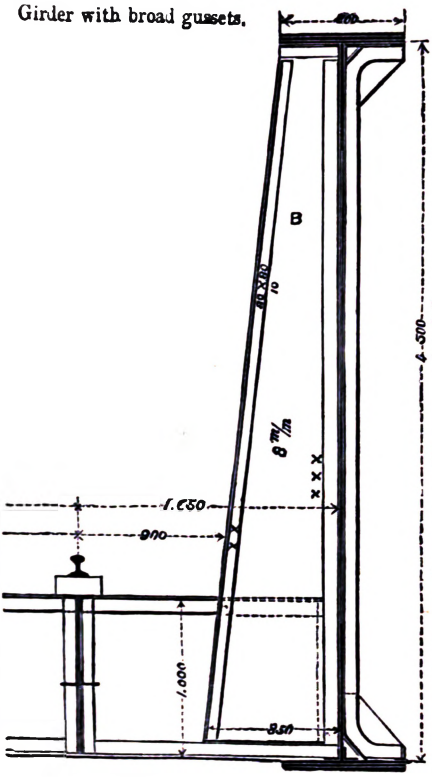
Weight a lineal mètre of flooring .. .. { of the cross-girders, 410$^{k}$ / of the minor girders, 320$^{k}$ } 730$^{k}$

Scale, 0·02.



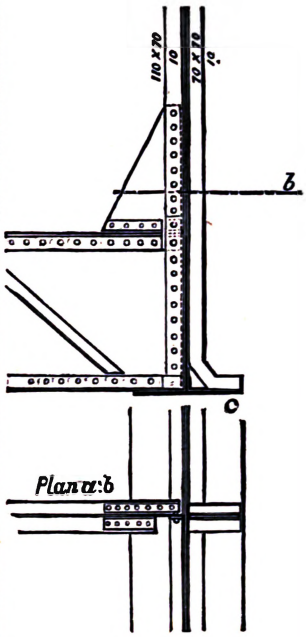

1601.

Girder with broad gussets.




1604.

Joint.



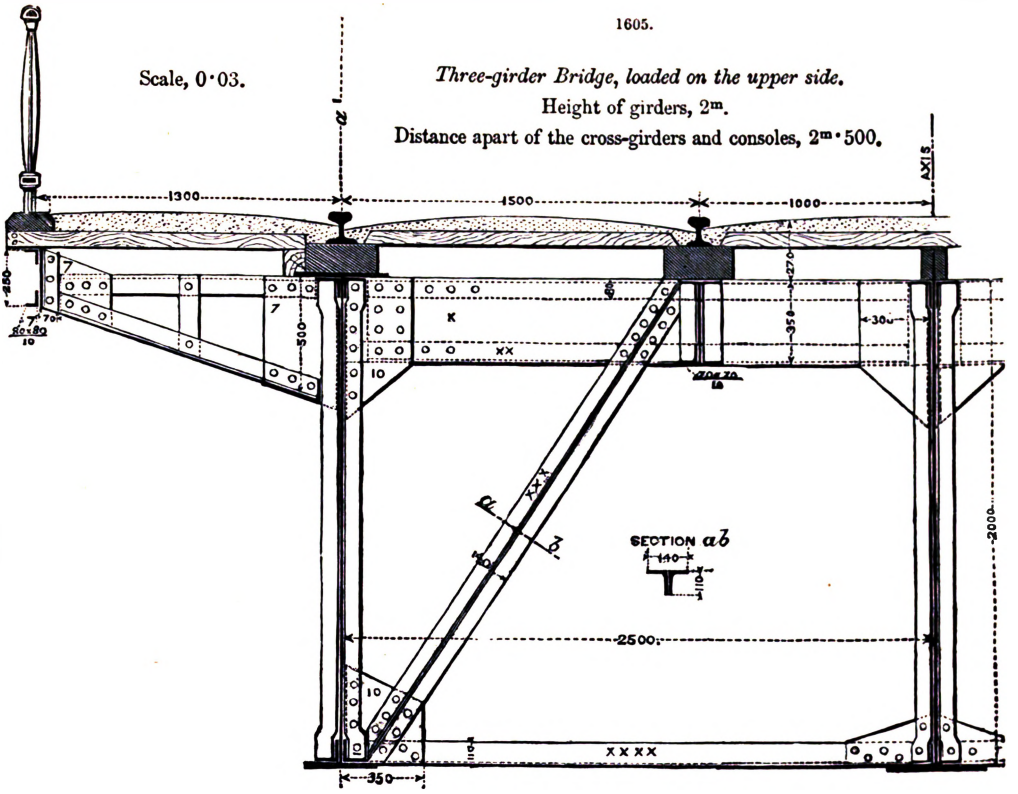
1605.

Scale, 0·03.

*Three-girder Bridge, loaded on the upper side.*

Height of girders, $2^m$.

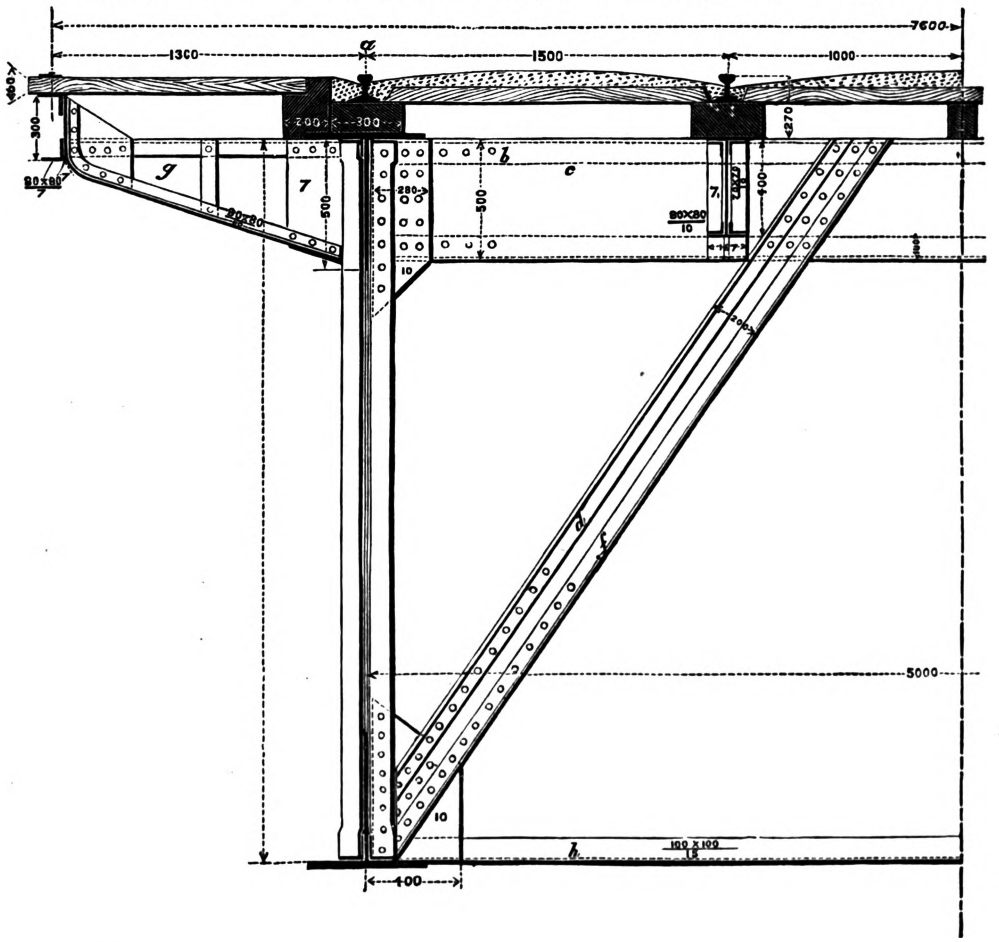
Distance apart of the cross-girders and consoles, $2^m \cdot 500$.




1606.

*Two-girder Bridge, loaded on the upper side.*

Height of girders, $3^m$. Distance apart of the cross-girders and consoles, $3^m \cdot 000$. Scale, 0·03.



the bridge, which may be the case in a certain degree when the principal girders are straight. The section of the iron is usually flat, because, of the two diagonals forming a Saint Andrew cross, there is always one which resists tension, whilst the cross-girders serve as compression-bars; besides, the compressed diagonal does not remain quite inactive when it is fixed in several points throughout its length, as is usually the case. When, on the contrary, the bars are left free throughout a considerable length, it is preferable to make them of T-iron, to avoid yielding.

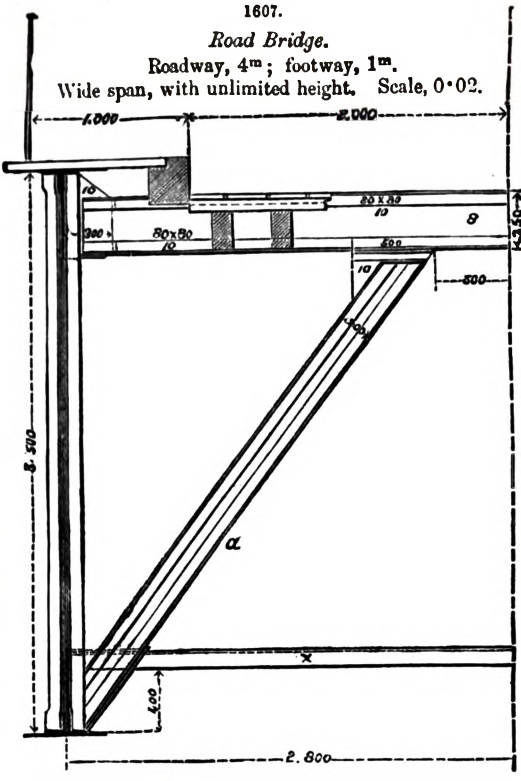
In bridges of small span—of less than 25 mètres, for example—the breadth of the flooring is a large fraction of the length, and the trussing may be omitted, because the rigidity of the flooring itself offers a sufficient resistance to transverse oscillations.

For a bridge loaded on the upper part, Figs. 1612, 1613, and Figs. 1580 to 1585, the horizontal trussing may weigh, according to the span, from 50 to 90 kilogrammes the lineal mètre of flooring under two lines of rails (bars of 160/12 to 200/16 millimètres), including the gussets.

1607.

*Road Bridge.*

Roadway, 4m; footway, 1m.
Wide span, with unlimited height. Scale, 0·02.




Cross-girder without strut.

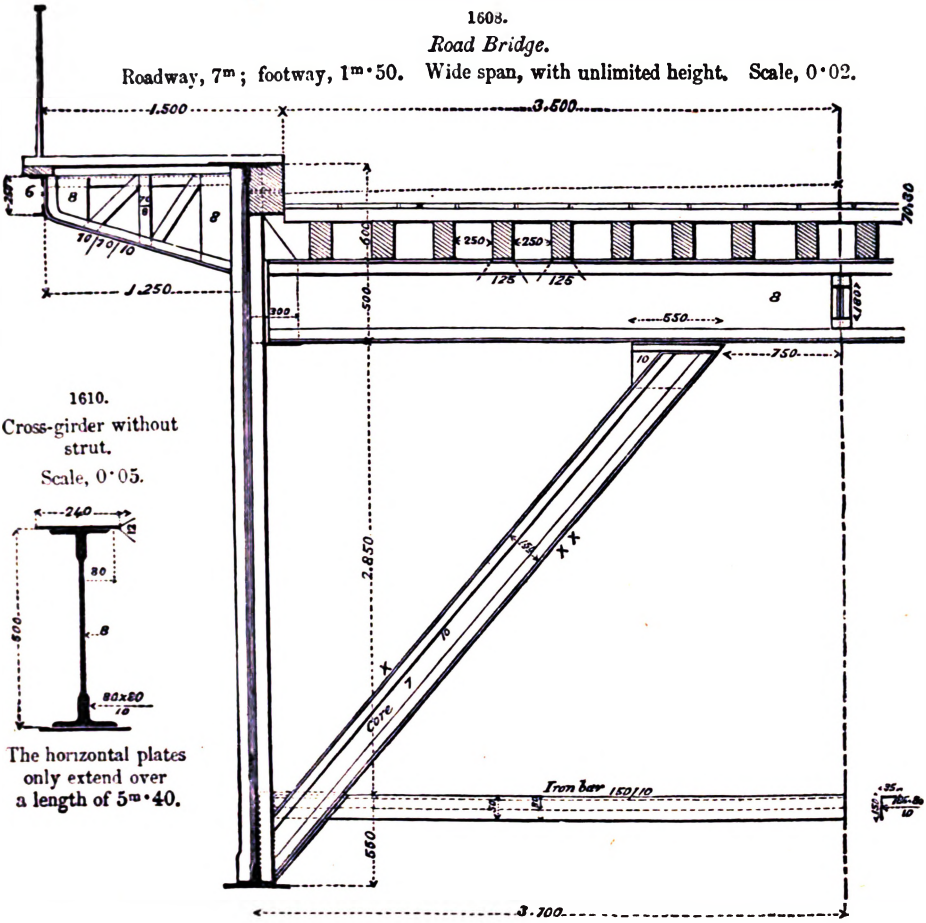
1611.

The horizontal plates $\frac{220}{10}$ only extend over a length of 3·80.

1608.

*Road Bridge.*

Roadway, 7m; footway, 1m·50. Wide span, with unlimited height. Scale, 0·02.




1610.

Cross-girder without strut.

Scale, 0·05.




The horizontal plates only extend over a length of 5m·40.

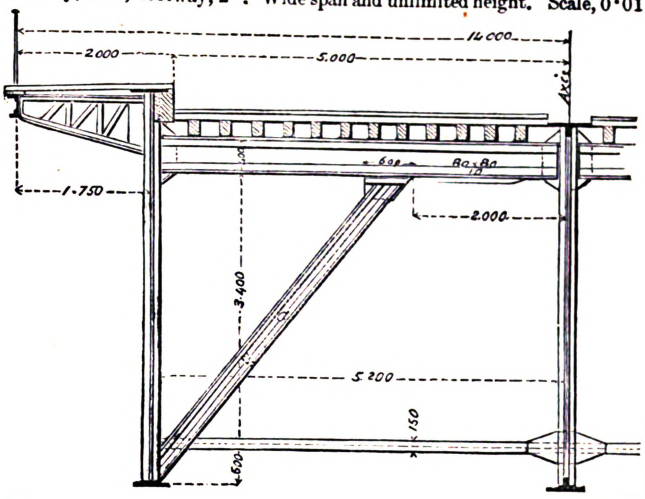
For a three-girder bridge, loaded on the lower part, we may reckon from 80 to 150 kilogrammes; for a two-girder bridge, loaded on the lower side, from 50 to 100 kilogrammes. Tubular bridges absorb the lineal mètre, from 130 (two-girder bridges) to 160 kilogrammes (three-girder bridges) and above, for their double trussing or cross-bracing, which, added to their great breadth, gives them a transverse rigidity greater than bridges of an equal span loaded on the upper part, and having corbels, could possess.

In ordinary road bridges the horizontal cross-bracing may be considerably inferior

1609.

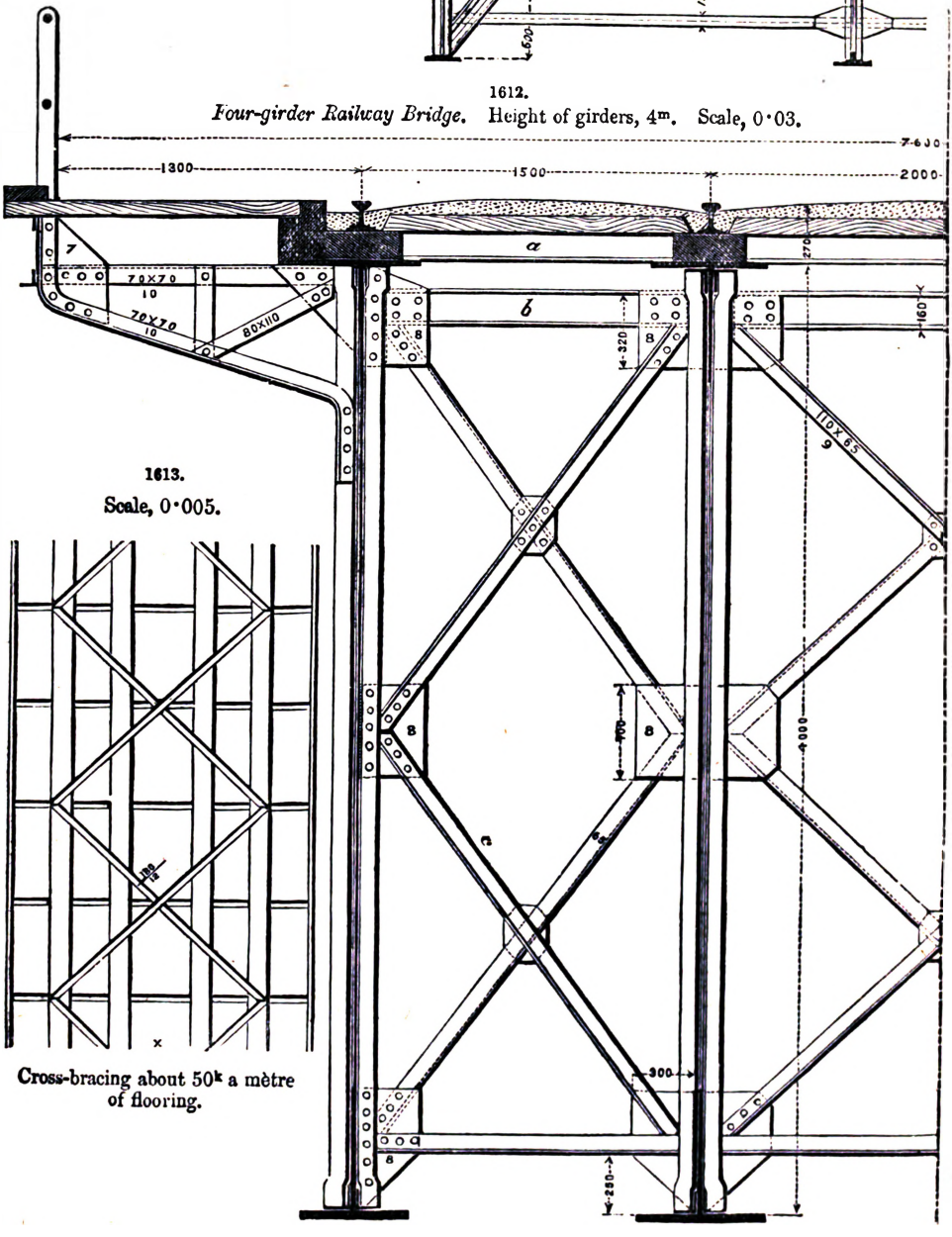
*Road Bridge.*

Roadway, 10m; footway, 2m. Wide span and unlimited height. Scale, 0·01




1612.

*Four-girder Railway Bridge.* Height of girders, 4m. Scale, 0·03.




1613.

Scale, 0·005.



Cross-bracing about 50k a mètre of flooring.

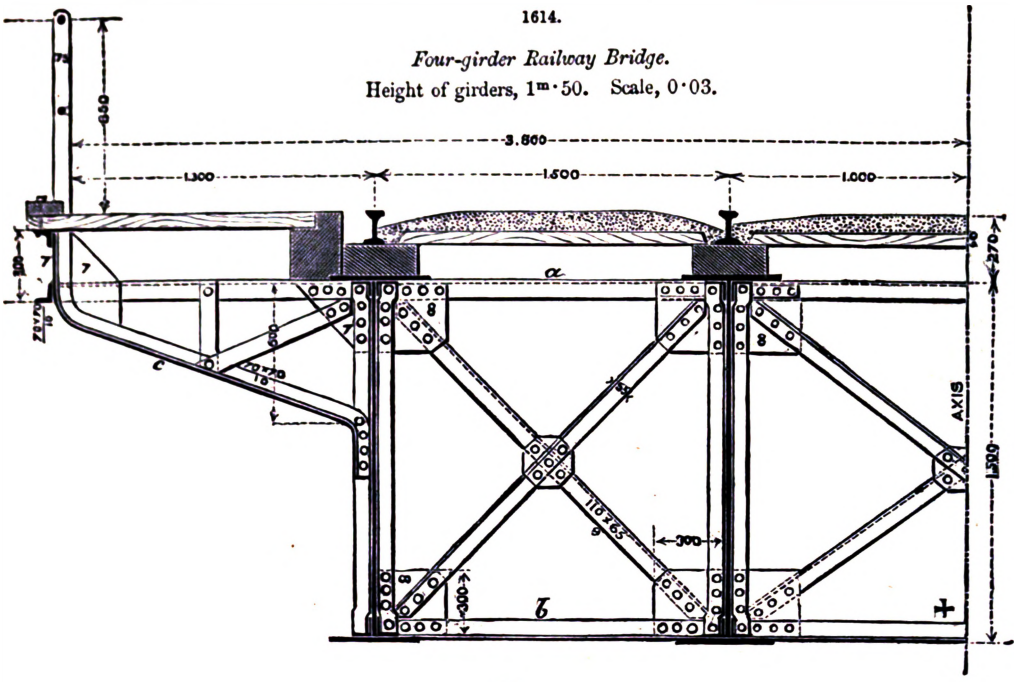
in strength to that required for railway bridges. Flat bars of 100/12 are in general amply sufficient.

27. In cases when the height allowed is unlimited, the lines of rails may rest upon the upper part of the girders. When the span is inconsiderable we shall have, generally, four principal girders, supporting directly the rails, as in Figs. 1612 to 1614; for in such cases the other pieces serve only

1614.

*Four-girder Railway Bridge.*

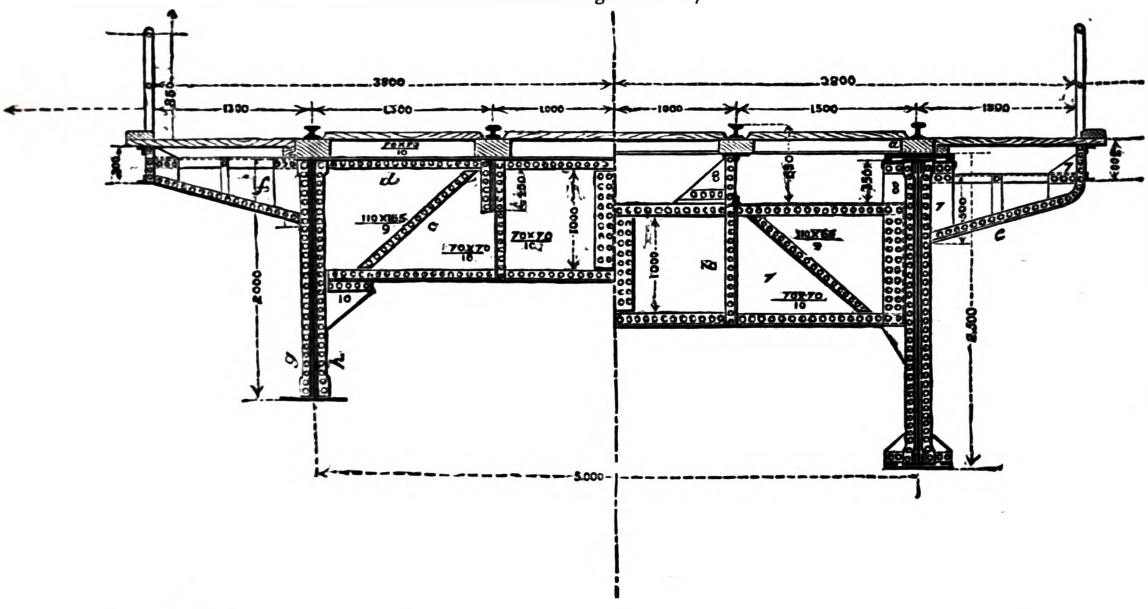
Height of girders, $1^{m} \cdot 50$. Scale, 0·03.




1615.

*Two-girder Railway Bridge, loaded on the upper side.*

Girders of moderate height. Scale, 0·02.




to tie the girders, and may be of small dimensions. But when the span is great, the saving in the secondary pieces should be sacrificed in favour of the more important saving which may be effected by reducing the number of the principal girders. One girder costs less than two that are only half loaded, and, besides, this one girder will be subject to the full strain only in the exceptional case of two trains crossing the bridge simultaneously. Figs. 1580 to 1585, and Figs. 1606, 1615, 1616, 1617, give examples of bridges of two girders of various heights, and, consequently, applicable to bridges of small and great span. Between two-girder and four-girder

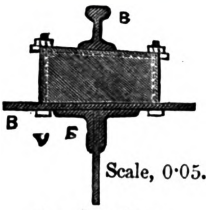
bridges are those of three girders, Figs. 1605 and 1618 to 1620, which require strong cross-girders, but less important than those of two-girder bridges.

When the height allowed is limited, the load is placed upon the lower part of the girders; in such cases the girders form the sides or parapets of the bridge when they are not very high, and when their height is great, advantage is taken of the circumstance to tie them on the upper part; this latter arrangement constitutes the tubular system. Figs. 1591 to 1598 are examples of three-girder bridges constructed according to the first method, and Figs. 1621 to 1624 are examples respectively of three-girder and two-girder tubular bridges. In the various kinds of bridges loaded on the lower part, we distinguish again those in which the height of the cross-girders is limited, and those in which this height is great, for this is of considerable importance when we regard the weight of the minor and cross girders. For example, in Figs. 1591, 1594, 1595, in which the cross-girders have a height of 0·220 mètre, this weight reaches 1350 kilogrammes the lineal mètre of flooring under two lines of rails; whilst in Fig. 1593, with a height of 0·850 mètre, it is reduced to 630 kilogrammes. A limited thickness obliges us to increase the number of cross-girders, and induces us to give the preference to three-girder rather than to two-girder bridges.

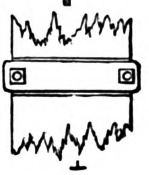
Regarded from the point of view of tying the principal girders, the distance between the cross-girders will be determined by the transverse rigidity of the former. Girders with narrow flanges may need to be tied every 2 mètres, or 2·50 mètres; whilst in large bridges, provided the cross-girders be strong and firmly fixed, they may be placed 4 mètres apart and even more.

1616.

Bolting of the sleepers upon the girders.




Scale, 0·05.

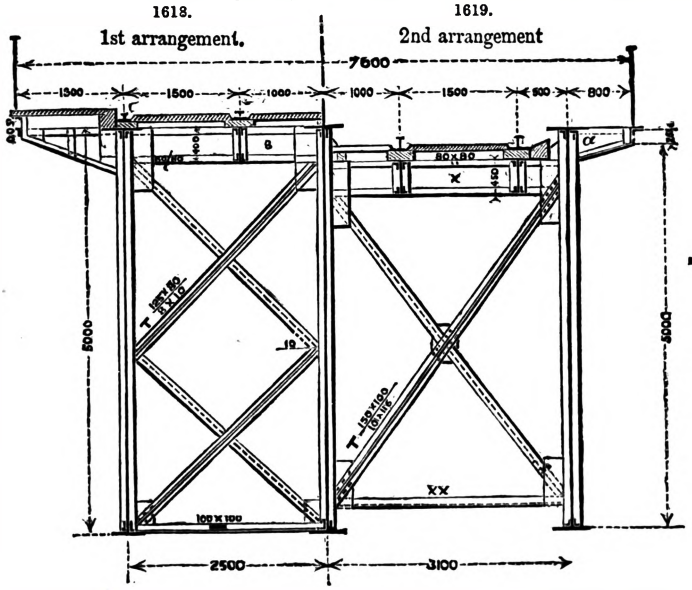


1617.

*Three-girder Railway Bridge, loaded on the upper side.*

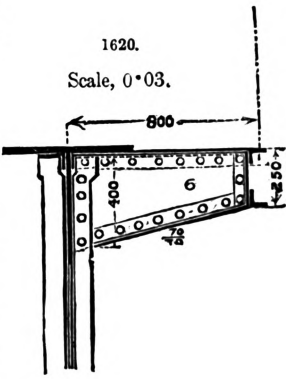
Height of girders, 5m. Distance between cross-girders, 3m·000. Scale, 0·01.

1618. 1619.




1620.

Scale, 0·03.




28. The weight of the various parts beside the principal girders may be taken generally as follows:—

*Weight of the parts beside the chief Girders and the horizontal Trussing, the lineal mètre of flooring under two lines of rails.*

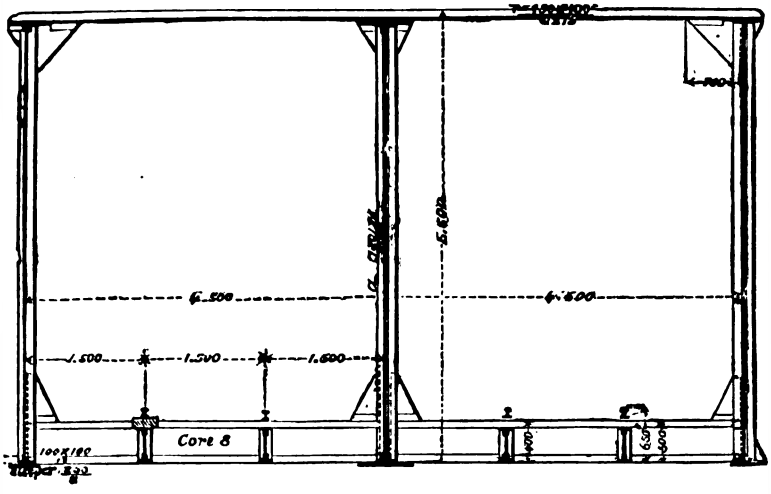
1. Loaded on the upper side.
   - Four-girder bridges.
     - Distance between cross-girders, 2 mètres: 320 to 450 kilogrammes, according as the height of the girders varies from 1·50 to 4·00 mètres;
     - Distance between cross-girders, 3 mètres: 260 to 350 kilogrammes, according as the height of the girders varies from 1·50 to 4·00 mètres;
   - Three-girder bridges: 460 to 800 kilogrammes, according as the height varies from 2 to 5 mètres;
   - Two-girder bridges: 540 to 920 kilogrammes, according as the height varies from 3 to 8 mètres;

2. Loaded on the lower side.
   - Three-girder bridges: 960 to 630 kilogrammes, according as the height of the cross-girders varies from 0·35 to 0·85 mètre;
   - Three-girder bridges; 1050 to 730 kilogrammes, according as the height of the cross-girders varies from 0·60 to 1·00 mètre;
   - Three-girder tubular bridges: 1050 to 730 kilogrammes with cross-girders of 0·35 to ·80 mètre;
   - Two-girder tubular bridges; 900.

We omit those exceptional cases of bridges loaded on the lower part, in which the height allowed is so limited as to render necessary very expensive arrangements.

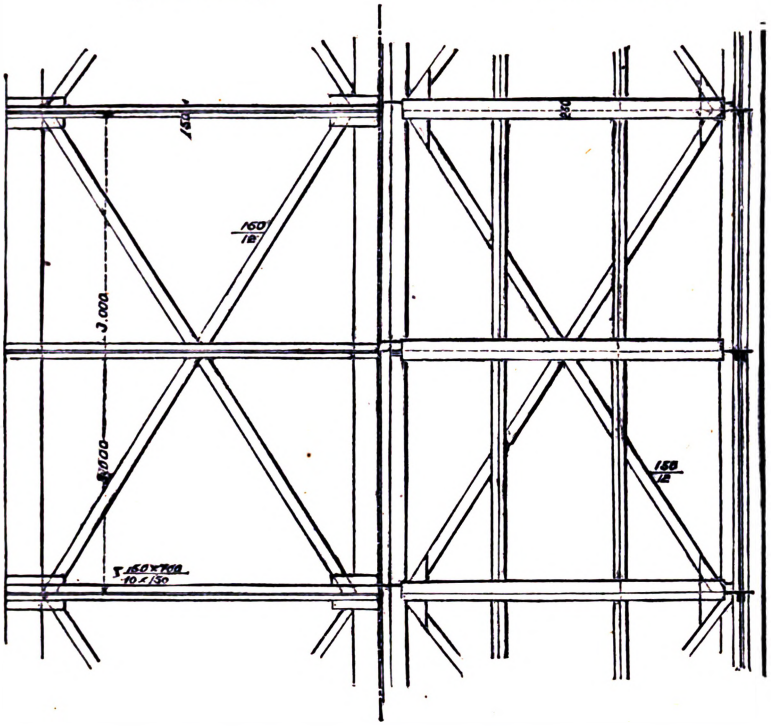
1621.

*Three-girder Tubular Bridge.* Scale, 0·01.




1622.

Top cross-bracing. Bottom cross-bracing.



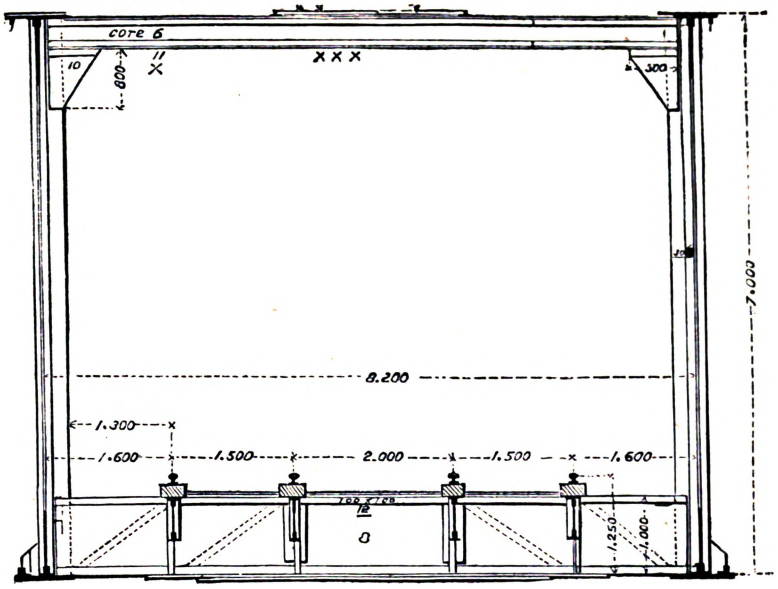

29. The planking of railway bridges is composed of planks 0·06 or 0·07 mètre thick. The longitudinal timbers supporting the rails are 0·13 or 0·15 thick by 0·25 or 0·30 broad. As the calculation of the timbers can be always easily made, it is useless for us to consider it here. Generally we shall have from $(0{\cdot}60)^2$ to $(0{\cdot}70)^3$ mètre, the lineal mètre of flooring under two lines of rails.

30. For ordinary road bridges we prefer wood in the construction of the flooring to corrugated iron, because with wood we may place the beams farther apart, which is a more economical arrangement. It is true that the wood will require to be sooner renewed, but that is a labour which is readily executed, even without interrupting the traffic. In Figs. 1607 to 1625, the planking is 0·07 mètre thick, and is covered with a boarding 0·03 mètre thick which serves the double purpose of protecting the planking, and of increasing its power of resisting by preventing a single plank from yielding beneath the weight of the wheel of a vehicle. The planking rests upon joists 0·250 mètre deep by 0·125 mètre broad, placed at distances of 0·375 mètre apart.

1623.

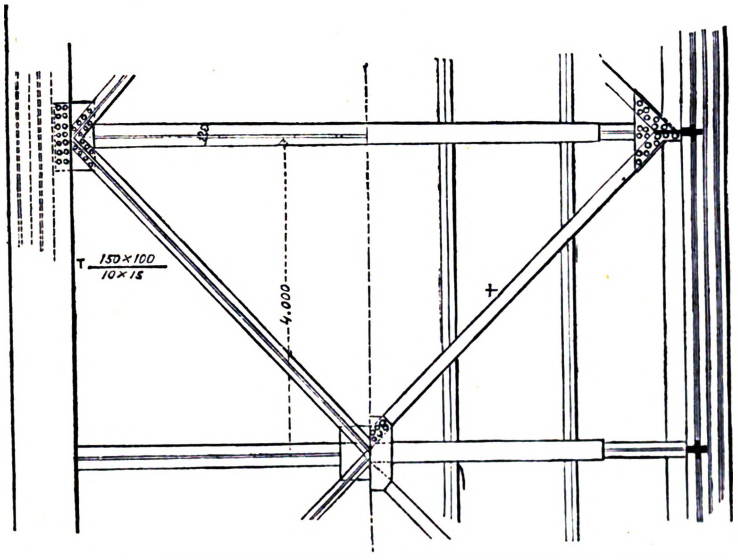
*Two-girder Tubular Bridge.*

Cross-bracing in T-iron. Cross-girder with vertical gussets, 660k. Scale 0·01.




1624.

Upper cross-bracing. Lower cross-bracing above the cross-girders.




When corrugated iron is employed, it may be 0·003 mètre thick for a distance of 1·40 mètre between the cross-girders, the ridges being 0·080 mètre in height and having a mean breadth of 0·160 mètre; but this iron does not resist well unless it is covered with a sufficiently thick layer of earth to prevent the wheels from concentrating their action upon a single ridge.

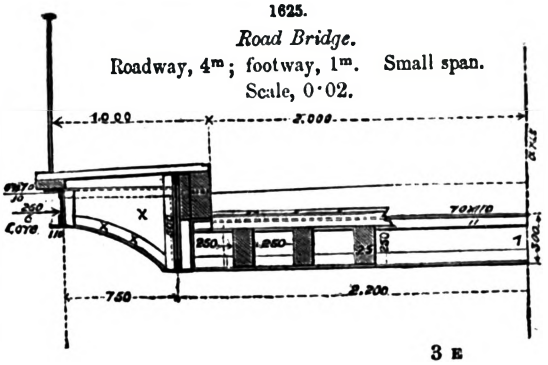
There yet remains for very important works the heavy but indestructible system of *brick arches*, springing from iron beams. But our purpose is only to study the most economical arrangements.

1625.

*Road Bridge.*

Roadway, 4m; footway, 1m. Small span.

Scale, 0·02.



31. The planking of the above-mentioned figures, cubes a square mètre, or has as its reduced thickness 0·183 mètre. With this planking, the proper distance between the cross-girders is 1·80 mètre. We may consider the cross-girders as subject to a maximum weight of 1000 kilogrammes

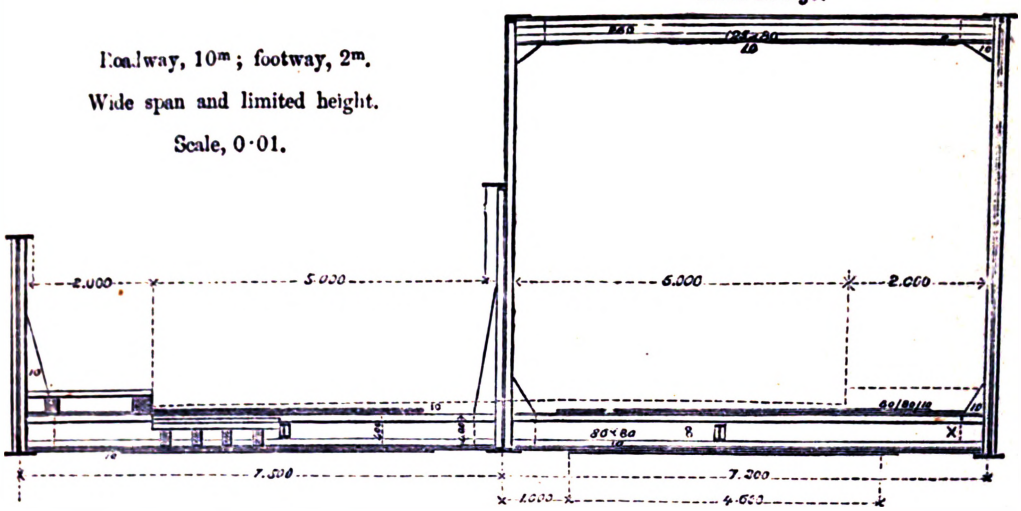
1626.

*Road Bridge.*

Roadway, 10m; footway, 2m.

Wide span and limited height.

Scale, 0·01.



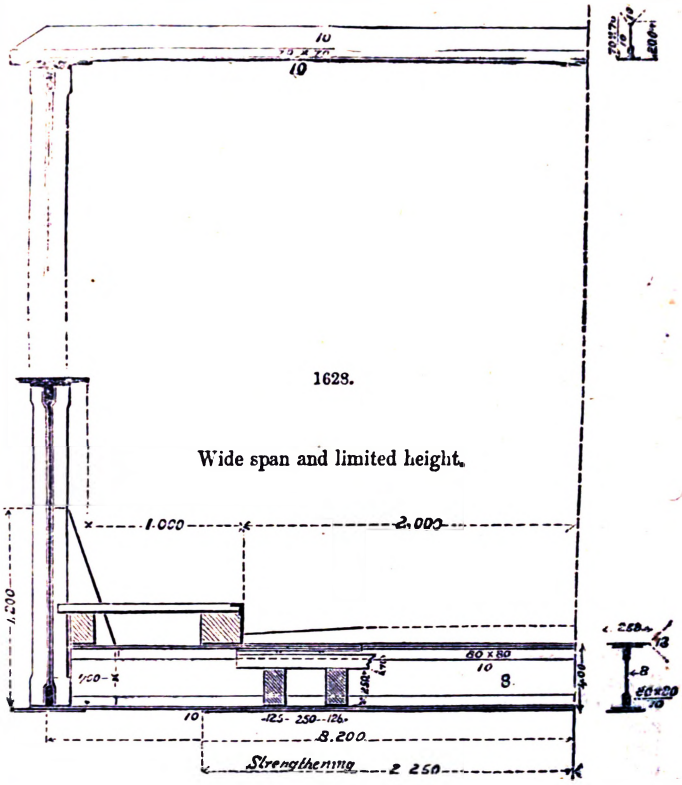

the lineal mètre (the layer of earth varying from 0·15 to 0·25 mètre), and to an accidental load of two wheels, each exerting a pressure of 3 tons, placed 1·50 mètre apart, and in the most unfavourable position, which gives the moment of rupture expressed by the formula in 10. When the bearing of the cross-girder exceeds 4 mètres, we must consider the case of two heavy vehicles passing in opposite directions. The wheels may vary in respective position, but as the ballast serves to distribute the pressure, we shall admit that the total weight of 12 tons for the four wheels, simultaneously situate upon the cross-girder, is distributed uniformly throughout its length. Table VII. gives for these conditions, some sections ready calculated. The weights include gussets similar to those in the figures already referred to, and suppose that the distance between the girders exceeds by 0·40 mètre their bearing.

Cross-girders of more than 8 mètres will generally be divided in their length by one or more of the principal intermediate girders.

1627.

*Road Bridge.*

Roadway, 4m; footway, 1m. Upper cross-girder for tubular bridge.




1628.

Wide span and limited height.

32. The figures referred to in 30 represent bridges of three different breadths:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6 mètres. | composed of | 4 mètres | of roadway | and two | footways | of | 1·00 mètre | each |
| 10 | " | " | 7 | " | " | " | 1·50 | " |
| 14 | " | " | 10 | " | " | " | 2·00 | " |

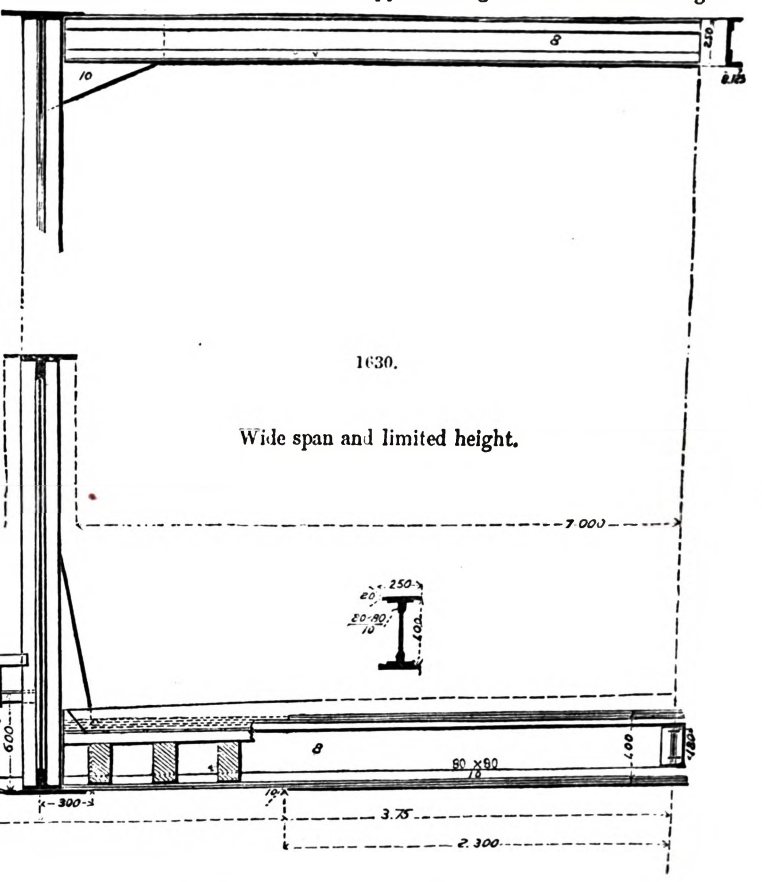
And for each of these breadths we may distinguish the cases of,—1, small span, which requires only a moderate thickness between the level of the road and the under-side of the girders; 2, wide span with unlimited height; and 3, wide span with limited height. This gives occasion

for nine different transverse sections, or rather for twelve, for Figs. 1626 to 1630 are double, and represent either girders loaded on the lower side or tubular bridges. Cross-girders supporting the road are always placed 1·80 mètre apart; but cross-girders used only as tie-beams, struts, and braces, are placed only at double intervals. In Figs. 1607 to 1611 there is, therefore, one out of every two cross-girders untrussed; but the want of this is compensated by an additional plate in the flanges. In Figs. 1608, and 1626 to 1630, the cross-girders, which are very long, are held in the middle of their length by longitudinal bars in double T-iron of 20 kilogrammes to the lineal mètre. In bridges of a rather wide span we add a horizontal cross-bracing of flat bars of 100/12 millimètres, and which, when fixed to the cross-girders, serves to prevent their lateral deflection. Tubular bridges require the cross-bracing both on the upper and the lower side.

1629.

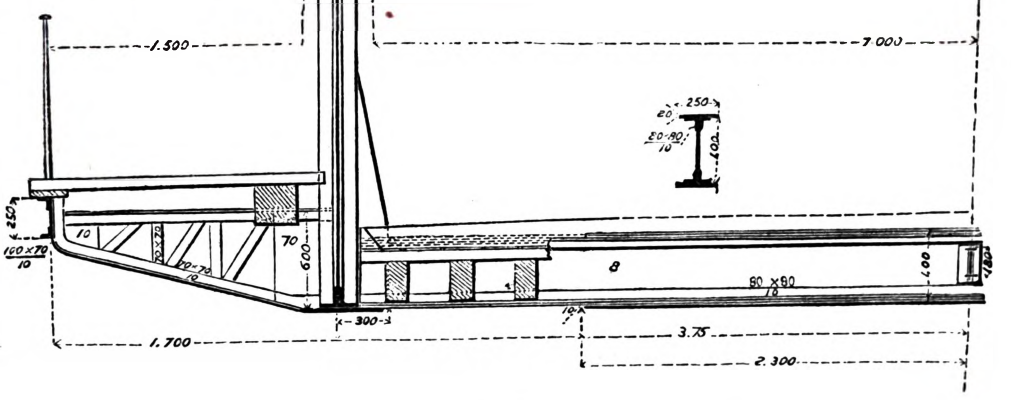
*Road Bridge.*

Roadway, $7^m$; footway, $1^m \cdot 50$. Upper cross-girder for tubular bridge.



1630.

Wide span and limited height.



The following Table gives the weight of iron the lineal mètre of flooring, not including the principal girders, for each of the transverse sections referred to above :—

| | | Kilogrammes. |
|---|---|---|
| Flooring, 6 mètres broad. | Small span | 340 |
| | Wide span, with unlimited height (girders 3·50 mètres high) | 460 |
| | " with limited height (girders loaded on the lower side) | 430 |
| | " " (tubular bridge) | 535 |
| Flooring, 10 mètres broad. | Small span | 430 |
| | Wide span, with unlimited height (girders 4·50 mètres high) | 810 |
| | " with limited height (girders loaded on the lower side) | 835 |
| | " " (tubular bridge) | 985 |
| Flooring, 14 mètres broad. | Small span | 745 |
| | Wide span, with unlimited height (girders 5 mètres high) | 970 |
| | " with limited height (girders loaded on the lower side) | 1260 |
| | " " (tubular bridge) | 1500 |

Those kinds which are applicable to wide spans admit, in the case of unlimited height, of truss-bars, the length of which increases with the height of the girders: it is for this reason that we have indicated the particular height for which the calculation has been made.

The weight includes the cross-bracing adopted in the cases of wide span; it includes also the parapets of 30 kilogrammes the lineal mètre, except in those cases in which the girders themselves form parapets.

33. *Loads applicable to the principal Girders.—Proportion between the Span, the Bearing, and the total Length.—Bearing-rollers.*—A girder of a considerable bearing is always calculated on the hypothesis that the loads are uniformly distributed, namely :—

1. A permanent load of $p$ kilogrammes the lineal mètre, throughout the whole length.
2. An accidental load of $p'$ kilogrammes the lineal mètre, throughout a certain length of the bearing.

*Loads p and p' applicable to Railway Bridges.*—Sometimes the dead weight $p$ is purposely increased by means of a thick layer of earth or ballast, for the purpose of deadening the vibrations caused by the rolling load $p'$; this, besides, allows us to make the lines of rails independent of the flooring, by placing them upon sleepers not fixed to the metal part of the bridge. But this is an exceptional arrangement; usually the dead weight of the indispensable parts is reduced, for the reason that the iron is capable of resisting the vibrations which are produced by the passage of the trains, when the girders are calculated for a strain of 6 kilogrammes the square millimètre. An increase of the permanent load may no doubt be favourable to the power of resistance in the material, but if it be adopted, it will only be logical to take for R a greater value than 6000000, for it is acknowledged that this coefficient offers perfect security in cases in which the vibrations are exerted in the usual manner. At any rate, we shall suppose only a thin layer of ballast to protect the planking from the burning coals dropped by the engine.

By adding the weight of the rails, of the timber, and the various pieces of the flooring, we may take as the average the lineal mètre of each of the chief girders, not including its own weight, the following permanent loads:—

| | | |
|---|---|---|
| Bridges loaded on the upper part. | of 4 girders: | $p_1$ = 500 to 600 kilogrammes. |
| | of 3 „ | 800 „ |
| | of 2 „ | 1200 „ |
| Bridges loaded on the upper part. | of 3 girders | outside girders: 800 to 700 kilogrammes, according as the thickness is great or otherwise. |
| | | middle girder: 1700 to 1400 kilogrammes, according as the thickness is great or otherwise. |
| | of 2 girders: | 1400 kilogrammes. |

To obtain $p$, we must add to $p_1$, given above, the weight $p_2$ of the girder itself a lineal mètre, a weight which it is of small consequence to know exactly, and which may be corrected, if it be deemed necessary, by a second calculation. When we wish to obtain only the net value, we may get rid of the weight $p_2$, by remarking that in general the weight of the girder a lineal mètre is, at least in the greater part, proportional to $(p + p')\,l$. Supposing, then, $p_2 = \mathrm{D}\,(p_1 + p_2 + p')\,l$, we obtain $p_2 = \dfrac{\mathrm{D}\,(p_1 + p')\,l}{p_1 - l\,\mathrm{D}}$; or by making $\mathrm{D}\,(p_1 + p')\,l = p_3$, $p_2 = \dfrac{(p_1 + p')\,p_3}{p_1 + p' - p_3}$; we can, therefore, deduce the weight $p_2$, found from the weight $p_3$, which is obtained by neglecting in the dead weight the weight of the girder itself. The result will not be strictly true, because the proportion $q$ of the rolling load to the total load is increased by the reduction of the latter; but the error is small, $q$ having but a slight influence except upon a few lattice-bars.

34. Let us now consider the moving load $p'$.

An engine with its tender may be placed upon a bridge of 10 mètres, and if the weight amounts to 60 tons, we shall have 6000 kilogrammes the lineal mètre for one line of rails, admitting, as we may for this length of span, that the load produces nearly the same effect as it would do if uniformly distributed.

Beyond a span of 60 mètres, we always suppose, in calculations, a load of 4000 kilogrammes.

Between 10 and 60 mètres, this assumed load should vary as follows:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Spans .. .. .. .. = | 10, | 20, | 30, | 40, | 50, | 60 mètres, and above. |
| Load P' (for a single line) = | 6000, | 5000, | 4600, | 4300, | 4100, | 4000 kilogrammes. |

A girder may have to support two rails, one rail, or a fraction of a rail, according to the system of flooring. The following Table gives the necessary information regarding this matter, omitting altogether rails which are not loaded.

| | | | Number of Rails supported by 1 Girder. | |
|---|---|---|---|---|
| | | | When both Lines are Loaded. | When 1 Line is Loaded. |
| | | | rail. | rail. |
| Bridges loaded on the upper side. | of 4 girders .. .. .. .. .. .. .. .. .. .. .. | | 1 | 1 |
| | of 3 girders | the outside girders being 5 mètres apart: middle girder .. | $\frac{6}{5}$ | $\frac{3}{5}$ |
| | | the outside girders being 5 mètres apart: one outside girder | $\frac{7}{5}$ | $\frac{7}{5}$ |
| | | the outside girders being 6·20 mètres apart: middle girder .. | $\frac{6}{6}$ | $\frac{6}{6}$ |
| | | the outside girders being 6·20 mètres apart: one outside girder | $\frac{7}{6}$ | $\frac{7}{6}$ |
| | of 2 girders | 5 mètres apart (Fig. 1606) .. .. .. .. .. | 2 | 1·70 |
| | | 6·40 mètres apart (Figs. 1580 to 1585) .. .. | 2 | 1·56 |
| Bridge loaded on the under side. | of 3 girders | middle girder .. .. .. .. .. .. .. | 2 | 1·00 |
| | | one outside girder .. .. .. .. .. .. | 1 | 1·00 |
| | of 2 girders .. .. .. .. .. .. .. .. .. .. .. | | 2 | 1·43 |

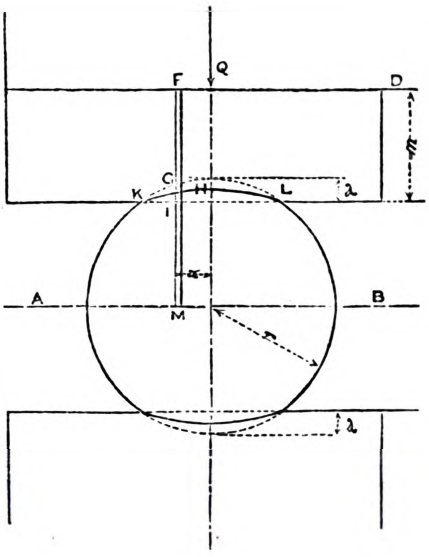
35 *Loads p and p' applicable to Road Bridges.*—The following Table gives the loads applicable to the girders of various kinds of bridges. The dead weights $p$ are calculated on the hypothesis that there is a layer of earth, or ballast, 0·20 mètre deep, and the moving loads $p'$ on the hypothesis that the roadway is loaded at the rate of 400 kilogrammes, and the footways at the rate of 200 kilogrammes, the square mètre.

| | Breadth. 6 Mètres. Figs. 1607, 1625, 1627. | Breadth, 10 Mètres. | | | Breadth, 14 Mètres. | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Fig. 1609. | | Fig. 1626. | |
| | | Outside Girder. | Middle Girder. | Figs. 1608, 1629. | Outside Girder. | Middle Girder. | Outside Girder. | Middle Girder. |
| $p$ for one girder, not including its own weight .. .. .. | kilos. 1300 | kilos. 1100 | kilos. 1900 | kilos. 2300 | kilos. 1600 | kilos. 2800 | kilos. 1450 | kilos. 3800 |
| $p'$ ditto .. .. .. .. | 1000 | 1000 | 1400 | 1700 | 1400 | 2000 | 1050 | 2700 |

36. *Bearing-rollers.*—Cast-iron plates are interposed between the girders and the masonry, where the former rest upon the abutments. For spans of more than 20 mètres, friction-rollers, or, as they are usually called, bearing-rollers, are placed between these plates and the girders to provide for the movement caused by the expansion of the metal. We may calculate in the following manner the maximum load which these rollers are liable to bear.

The girder is fixed in the direction of C D, Fig. 1631, to a plate, the thickness of which $= \epsilon$, resting upon rollers having a diameter of $2r$, which, in their turn, rest upon a lower plate, cemented into the masonry. The diametrical plane A B undergoes no distortion, it only sinks in consequence of the depression at the bottom; if we admit that the face C D also remains plane after compression, the planes C D and A B will have approached each other by the quantity $\lambda$, on account of the pressure Q exerted by the girder, and supposed collected upon 1 lineal mètre of roller. The lower face of the plate offers a depression into which the roller penetrates, and which is itself flattened. The value of the ratio $\frac{GH}{HI}$ of the compression of the roller to that of the plate, for an elementary prism F M, is $\frac{GH}{HI} = \frac{GM}{FI} = \frac{\sqrt{r^2 - x^2}}{\epsilon}$. To find H I, for example, we deduce from this proportion $\frac{GH + HI}{HI} = 1 + \frac{\sqrt{r^2 - x^2}}{\epsilon}$; or G H + H I, or G I $= \lambda - r + \sqrt{r^2 - x^2}$, and, consequently, denoting the modulus of elasticity by E, the portion of the load which the elementary prism F M supports will be $dQ = E \cdot \frac{HI}{\epsilon} = E \frac{\lambda - r + \sqrt{r^2 - x^2}}{\epsilon + \sqrt{r^2 - x^2}} dx$.

1631.




To determine $\lambda$, we remark that the metal must not be subjected to a strain greater than R the unity of section, so that $\lambda$ cannot exceed the value $\frac{R}{E}(\epsilon + r)$, which value will be substituted in the integral $Q = 2E \int_0^{\sqrt{\lambda(2r - \lambda)}} \frac{\lambda - r + \sqrt{r^2 - x^2}}{\epsilon + \sqrt{r^2 - x^2}} dx$.

Now the value of the integral of the form $\int \frac{A + \sqrt{r^2 - x^2}}{B + \sqrt{r^2 - x^2}} dx$ is

$$\int \frac{A + \sqrt{r^2 - x^2}}{B + \sqrt{r^2 - x^2}} = C + x + 2(B - A) \tan.^{-1} \frac{\sqrt{r^2 - x^2}}{x - r} + Z,$$

C being the arbitrary constant, and the term Z being equal to

$$\frac{B(A - B)}{\sqrt{r^2 - B^2}} \log._\epsilon \frac{\frac{B\sqrt{r^2 - x^2}}{x -} - r - \sqrt{r^2 - B^2}}{\frac{B\sqrt{r^2 - x^2}}{x - r} - r + \sqrt{r^2 - B^2}}, \text{ in the case in which } r > B;$$

to $\frac{2(r - A)(x - r)}{r - x + \sqrt{r^2 - x^2}}$, in the case in which $r = B$; and to

$$\frac{2B(A - B)}{\sqrt{B^2 - r^2}} \tan.^{-1} \frac{\frac{B\sqrt{r^2 - x^2}}{x - r} - r}{\sqrt{B^2 - r^2}}, \text{ when } r < B.$$

Usually, we have E = 0·100 mètre, and the diameter $2r$ of the rollers = 0·150 mètre. It will, therefore, be the last expression of Z that we shall have occasion to apply, and by calculating the definite integral which gives the value of Q, we obtain

$$Q = 2E\left\{\sqrt{\lambda(2r-\lambda)} - 2(\epsilon + r - \lambda)\left[\tan.^{-1}\frac{r-\lambda}{r-\sqrt{\lambda(2r-\lambda)}}\right.\right.$$

$$\left.\left. - \frac{\pi}{4} - \frac{\epsilon}{\sqrt{\epsilon^2 - r^2}}\left(\tan.^{-1}\frac{r + \dfrac{\epsilon(r-\lambda)}{r-\sqrt{\lambda(2r-\lambda)}}}{\sqrt{\epsilon^2 - r^2}} - \tan.^{-1}\frac{\epsilon + r}{\sqrt{\epsilon^2 - r^2}}\right)\right]\right\}.$$

For R = 6,000,000 and E = 8,000,000,000, a value applicable to thick cast-iron plates, the formula gives Q = 36370 kilogrammes the lineal mètre of roller, say 24 kilogrammes the square centimètre of diametrical section: this value we shall adopt as a maximum.

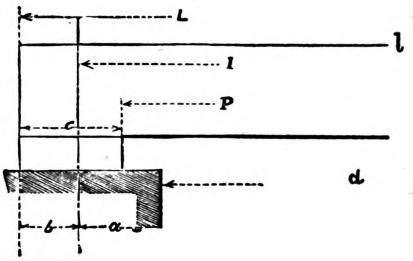
But when there are several rollers it is difficult to load them all equally. In order that no roller may exceed its limit of elasticity, it is essential that the bed-plates be fixed with care; the keys or bolts which hold them should, as far as possible, be tightened in an equal degree while the trial load is upon the bridge. When the distance of the load has modified the deflection of the girder, the pressure will be unequally distributed between the rollers; but this is no longer of consequence, because the rollers are greatly eased of the total weight. But in practice, a certain latitude must be allowed; and we should consider that the pressure has always a tendency to concentrate itself towards the facing of the abutment. If we admit that the centre of pressure, under a full load, may move forwards along 0·60 of the bearing upon the abutment, reckoning from the end, the mean pressure will be $\frac{5}{8}$ of the maximum 24 kilogrammes, say 15 kilogrammes the square centimètre of diametrical section of the rollers. If this pressure be referred to the total surface of the plates, it will be necessary to deduct the play of the rollers, and we must then reckon upon about 13 kilogrammes.

The evil of imperfect bed-plates cannot be remedied by increasing indefinitely the number of the rollers; for, under a full load, the extreme rollers support hardly anything. And, even if a roller should be subjected to a strain a little too great, the consequence will, in general, be of small importance.

In bridges of several spans, or bays, upon very high piers, the rollers should turn freely in order that the expansion of the iron may not cause a great horizontal strain upon the masonry. The bed-plates should be as equal as possible in all respects, both when the bridge has no load upon it and when it is fully loaded; and there is but one case in which the resultant of the pressures will, in any considerable degree, be diverted from the middle of the face of the support, namely, when the load is applied to one only of the contiguous bays. This case allows us to reckon upon the maximum pressure of 24 kilogrammes, or near it, for the full load, say 20 kilogrammes after having made the deduction for the play between the rollers.

37. *Relation between the Span, the Bearing, and the total Length.*—From what precedes, reckoning upon 13 kilogrammes the square centimètre, the bearing $c$, Fig. 1632. of a girder upon the abutment may be calculated by the formula $c = \frac{(p+p')L}{260000\,\beta}$, L being the total length of the girder (single bay), and $\beta$ the breadth of the plates or the bearing length of the rollers, which usually exceeds by 0·14 mètre the breadth of the flange of the girder, in the case of moderate span. For very large bridges, it will be preferable to increase $\beta$, and perhaps also the diameter of the rollers, in order that they may offer more elasticity to lessen the effect of the inclination produced by the deflected girder.

1632.




L, Length of the girder. I, Real bearing P, Apparent bearing. $d$, Span.

In general, supposing that the dimension $b$ of the figure is 0·60 of $c$, the total length L of the girder should be made = 1·045 $l$.

As to the ratio of the real bearing $l$ to the span $d$, it depends upon the dimension $a$, which should, in the first place, be at least equal to 0·40 $c$, and, in the second place, sufficient to keep the resultant of the pressures at a suitable distance from the facing of the abutment, and to prevent a crushing of the masonry. This condition depends itself upon the dimensions and talus of the abutment; but we shall generally do right by making $a = 0{\cdot}025\,d$.

Thus, to recapitulate, in calculations for bridges, we shall adopt $l = 1{\cdot}050\,d$ and

$$L = 1{\cdot}045\,l = 1{\cdot}0973\,d.$$

We shall usually consider the mean weight of the lineal mètre of girder in reference to the total length L. If we obtain the total weight P by a direct measurement including the ends of the girder, $\frac{P}{L}$ will be the mean weight; we shall take, on the contrary, $\frac{P'}{l}$, if the weight P′ results from a theoretical formula which supposes the length of the girder to be $l$, subject to the corrections necessary to take into account, according to the case, the ends of the girder. To obtain the weight in reference to the span, we must multiply the weight found for the mètre of total length, by 1·0973 or 1·10.

38. In *Skew bridges*, the normal span being $d$, and the angle of the skew being $\alpha$, the skew span will be $\frac{d}{\sin.\,\alpha}$, the real bearing $1{\cdot}05\,\frac{d}{\sin.\,\alpha}$, and the total length of the girders $1{\cdot}0973\,\frac{d}{\sin.\,\alpha}$. This

case presents no difficulty; the cross-girders are normal to the chief girders; some of them at the extremities are short, and rest upon an oblique piece which holds together the ends of the girders along the abutment. The first complete cross-girder forms with this oblique piece and the principal girder an unyielding triangle, which allows us to have recourse to a less expensive system of counter-bracing than would be required for a straight bridge of the same span. Beyond this difference, in the matter of calculating the weight and the resistance, a skew bridge and a straight bridge of the same span are alike.

The bridge, Figs. 1633, 1634, erected near Calcutta, was constructed according to the system of bridge-building introduced and practised by A. Sedley. The span, Fig. 1633, is 75 ft., and the structure was calculated to support a moving load of 120 lbs. to the sq. ft. of roadway. The total weight, including rods, girders, and Mallet's buckled-plates, is 30 tons. The iron was proved to 20 tons to the sq. in. of cross-sectional area; the tension or suspension bars are of the best Bowling iron. The cantilevers have merely the effect of increasing the range of the piers, and if the suspension-rods support the lattice-girder without destroying its perfect contact across and on each of the two brackets, the system is reduced to a lattice-girder resting on supports.

*Hydraulic Swing Bridge over the River Ouse.*—The information that we give respecting this bridge is taken from 'Proceedings of I. M. E.,' August, 1869.

This bridge was designed by Harrison, the engineer of the North-Eastern Railway. Near the bridge there was no supply of hydraulic power, and the total power required was too great to be supplied by hand labour. It was further necessary, on account of the position of the swing bridge, either to convey the power to the centre pier by a pipe under the bed of the river, or to produce it upon the pier by placing a steam-engine within the pier itself; and the latter plan was the one adopted.

The construction of the Ouse Bridge is shown in Figs. 1635 to 1646. Figs. 1635, 1636, show an elevation and plan of the swinging portion. Fig. 1637 is a vertical transverse section at the centre pier, showing the engine-room and accumulator, which are situated within the centre pier; and Fig. 1639 is a plan of the centre pier at the level of the engine-room, showing the arrangement of the driving-gear with the steam-engines and hydraulic engines. Fig. 1640 is an enlarged section of one half of the engine-room, and Fig. 1641 a sectional plan of the accumulator. Figs. 1647, 1648, are a plan and elevation of the hydraulic engines for turning the bridge; and Figs. 1643 to 1646 show the gear at the two extremities of the bridge for working the adjusting-supports and the locking bolts.

The total length of the bridge, fixed and movable, is 830 ft. The fixed portions consist of five spans of 116 ft. each from centre to centre of piers. The bridge being for a double line of railway, each span is composed of three wrought-iron plate-girders, the centre girder having a larger section to adapt it for its greater load; these girders have single webs, and are 9 ft. deep in the centre. The total width of the bridge from outside to outside is 31 ft. Each of the piers for the fixed spans consists of three cast-iron cylinders of 7 ft. diameter and about 90 ft. length. The depth from the under-side of the bridge to the bed of the channel in the deepest part is about 61 ft. The headway beneath the bridge is 14 ft. 6 in. from high-water datum, and 30 ft. 6 in. from low water.

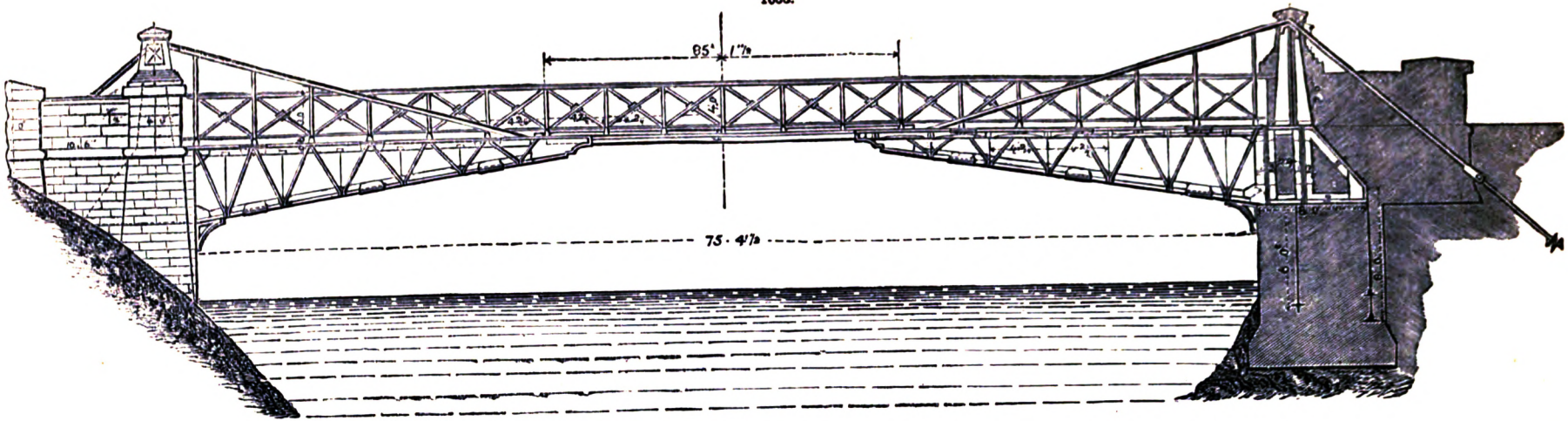
The swinging portion of the bridge, Figs. 1635, 1636, consists of three main wrought-iron girders, 250 ft. long, and 16 ft. 6 in. deep at the centre, diminishing to 4 ft. deep at the ends. The centre girder is of larger sectional area than the side girders, and instead of being a single web is a box-girder 2 ft. 6 in. in width, Fig. 1640, with web-plates $\frac{7}{16}$ to $\frac{5}{16}$ in. in thickness, and the top and bottom booms contain together about 132 sq. in. section. The roadway is carried upon transverse wrought-iron girders resting upon the bottom flanges of the main girders, Figs. 1640 and 1644. In the centre of the bridge the main girders are stayed by three transverse wrought-iron frames securely fixing them together; and over the top of these frames a floor is laid, from which the bridgeman controls the movements of the bridge.

An annular box-girder A A, 32 ft. mean diameter, is situated below the centre of the bridge and forms the cap of the centre pier, Figs. 1637 and 1640; this girder is 3 ft. 2 in. in depth and 3 ft. in width, and rests upon the top of six cast-iron columns, each 7 ft. diameter, which are arranged in a circle and form the centre pier of the bridge. Each of these columns has a total length of 90 ft., being sunk about 29 ft. deep in the bed of the river. A centre column B B, 7 ft. diameter, is securely braced to the six other columns by a set of cast-iron stays, which support the floor of the engine-room. This centre column contains the accumulator C, Fig. 1637, and forms the centre pivot on which the bridge rotates.

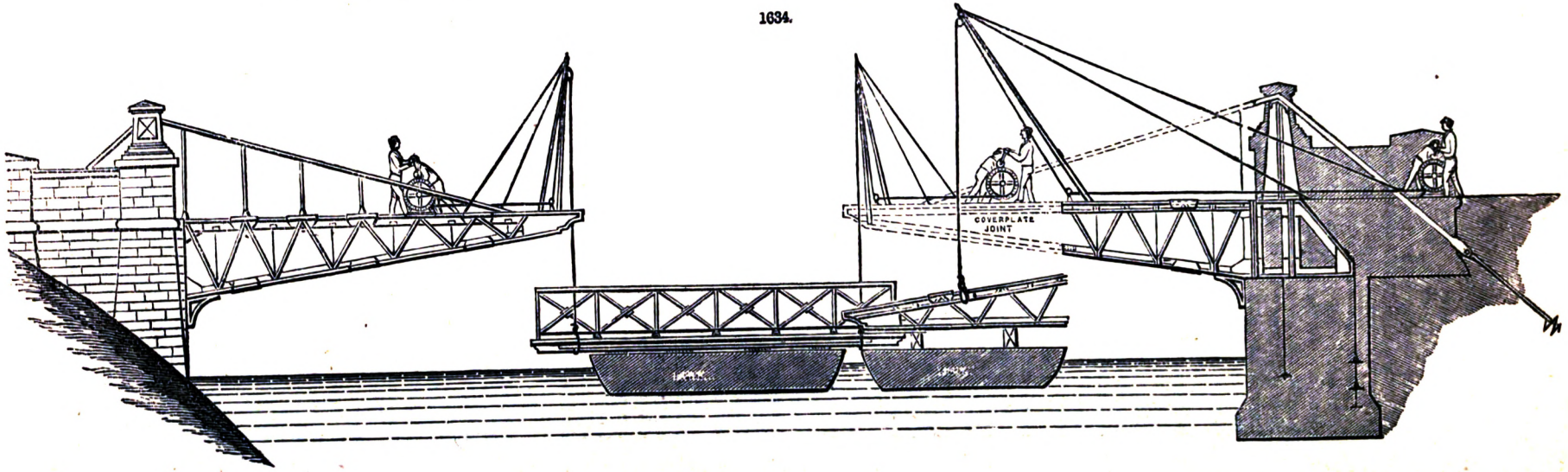
The weight of the swing bridge is 670 tons. There is no central lifting-press, and the entire weight rests upon a circle of conical live rollers E E, Figs. 1637 and 1640. These are twenty-six in number, as shown in the plan, Fig. 1638; they are each 3 ft. diameter with 14 in. width of tread, as shown in Fig. 1642, and are made of cast iron hooped with steel. They run between the two circular roller-paths D D, 32 ft. diameter and 15 in. broad, which are made of cast iron faced with steel; the axles of the rollers are horizontal, and the two roller-paths are turned to the same bevel.

The turning motion is communicated to the bridge by means of a circular cast-iron rack G, Fig. 1640, 12½ in. wide on the face and 6½ in. pitch, which is shrouded to the pitch-line and is bolted to the outer circumference of the upper roller-path. The rack gears with a vertical bevel-wheel H, which is carried by a steel centre-pin J supported in the lower roller-path; and this wheel is driven by a pinion connected by intermediate gearing with the hydraulic engine. There are two of these engines, duplicates of one another, which are situated at K K in the engine-room, Figs. 1639, 1640; and either of them is sufficient for turning the bridge, the force required for this purpose being equal to about 10 tons applied at the radius of the roller-path. Each hydraulic engine is a three-cylinder oscillating engine, as shown in Figs. 1647, 1648, with simple rams of 4½ in. diameter and 18 in. stroke. These engines work at forty revolutions a minute with a pres-

1633.

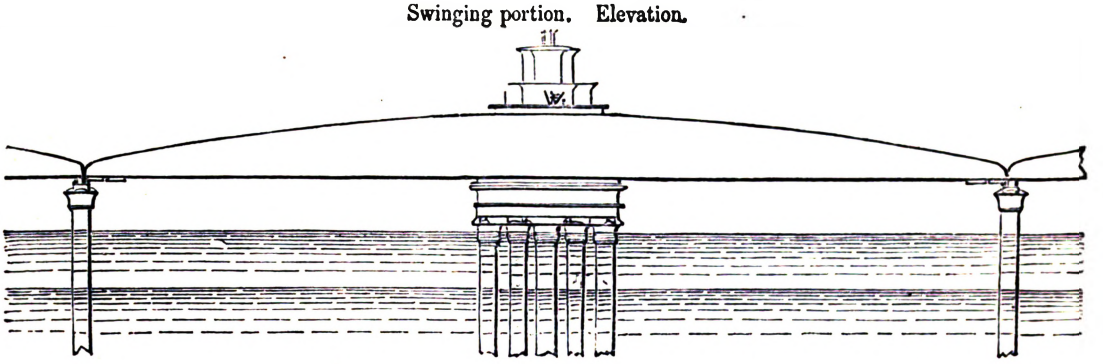



1634.

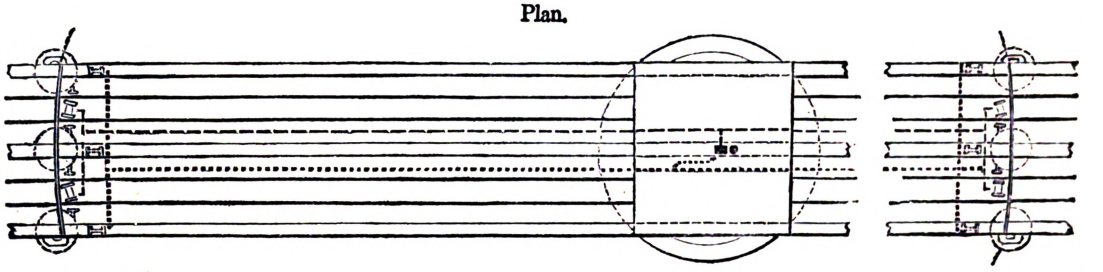


sure of water of 700 lbs. an inch, and are estimated at 40 horse-power each. The steam-engines for supplying the water-pressure are also in duplicate, situated at L L, Fig. 1639, and are double-cylinder engines driving three-throw pumps of 2¾ in. diameter and 5 in. stroke, which deliver

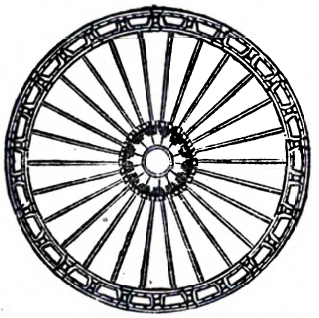
1635.
Swinging portion. Elevation.



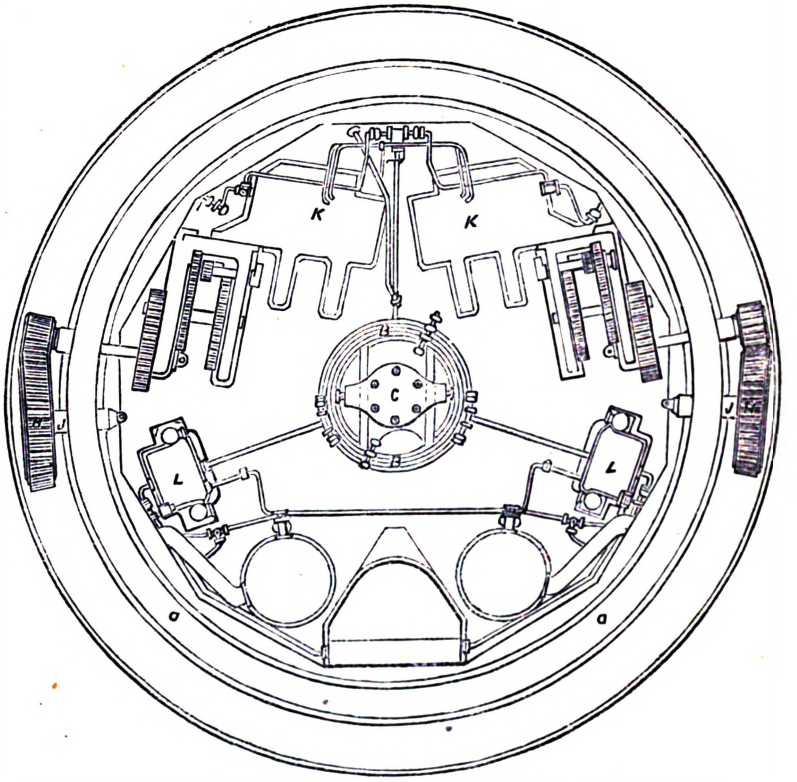
1636.
Plan.



1638.
Plan of roller-frame and rollers in centre pier.



1639.
Plan of centre pier and engine-room.




into the accumulator. The steam-cylinders are 8 in. diameter and 10 in. stroke, each engine being 12 horse-power.

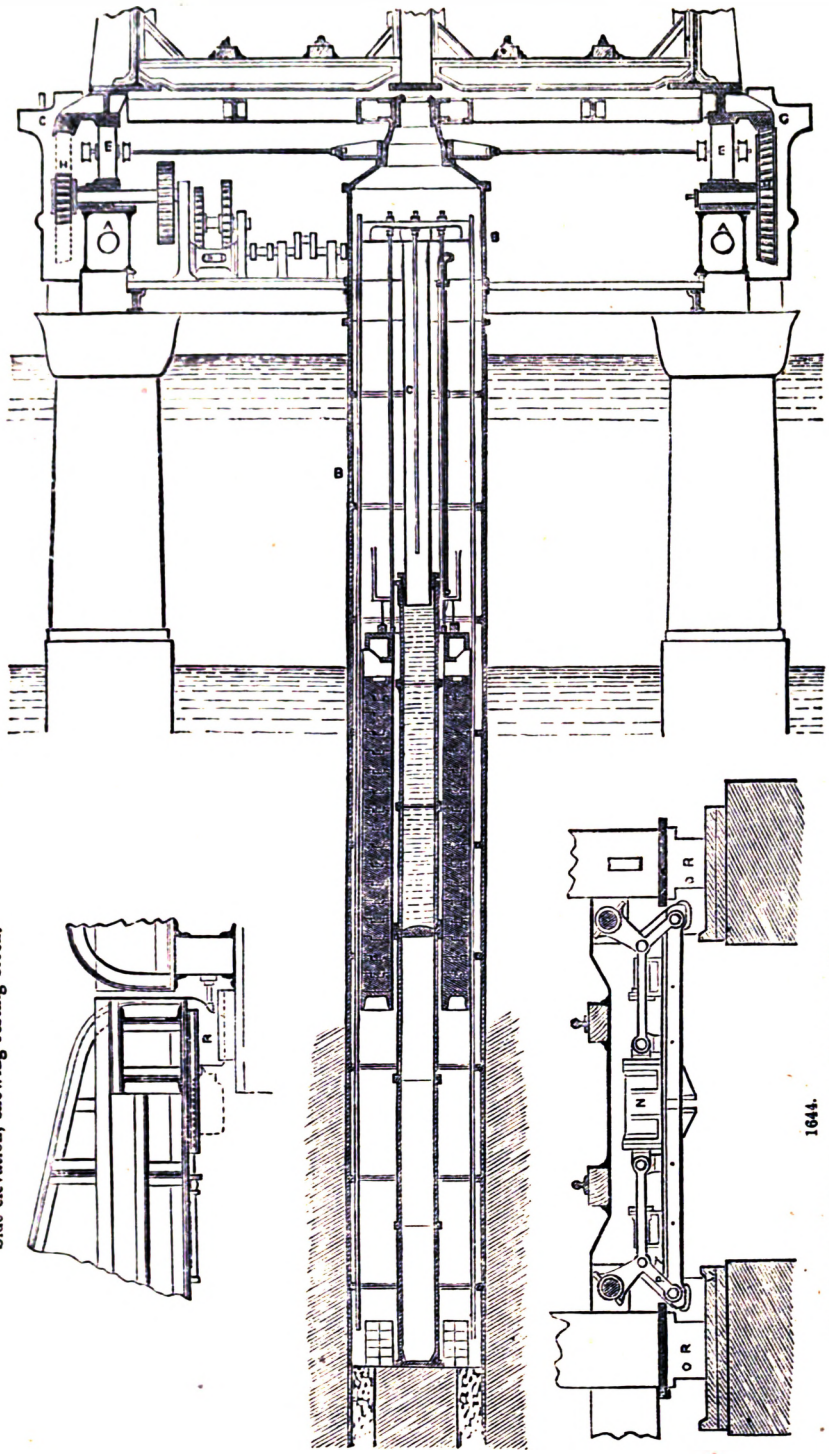
The accumulator C, Fig. 1637, shown also in the sectional plan, Fig. 1641, has a ram 16½ in. diameter with a stroke of 17 ft.; it is loaded with a weight of 67 tons, composed of cast-iron segments suspended from a cross-head and working down inside the cylindrical casing formed by the centre cylinder of the pier. A pair of cross-beams M M are fixed to limit the rise of the weight.

For the purpose of obtaining a perfectly solid roadway when the bridge is in position for the passage of trains, and also for securing the perfect continuity of the line of rails, the following arrangement is adopted, shown in Figs. 1643 to 1646. Each extremity of the bridge

is lifted slightly by a horizontal hydraulic press N, Figs. 1643, 1644, acting upon the levers P P which form a toggle-joint; the press has two rams acting in opposite directions upon two toggle-joint levers, which are connected by a horizontal bar Q, and this bar is confined to a

1637.

Section of centre pier and engine-room.




1646.

Side elevation, showing resting-block.

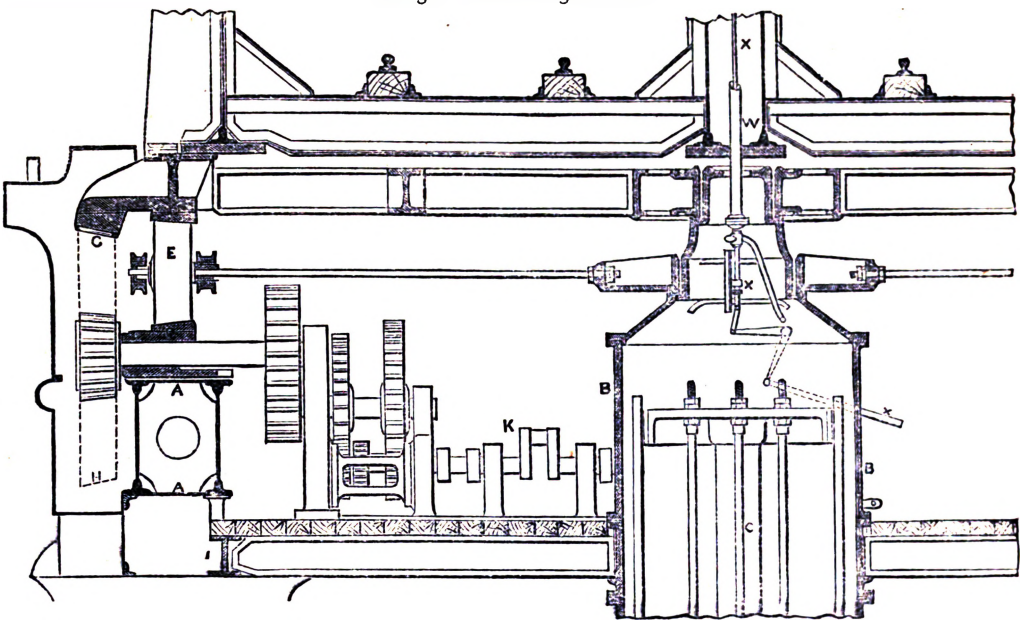
1644.

End elevation, showing resting-blocks and lifting-gear.

vertical movement by a stud sliding in a vertical guide, so as to ensure an exactly parallel action of the two toggle-joint levers, in order thereby to lift the bridge end exactly parallel. While the end of the bridge is thus held lifted, the three resting-blocks R R, one under each

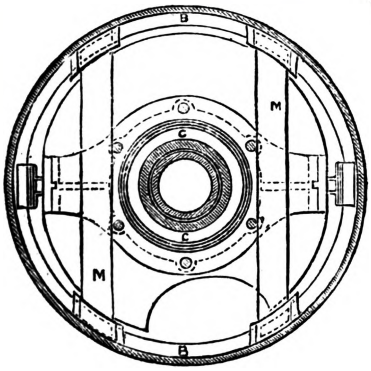
1640

Enlarged section of engine-room.



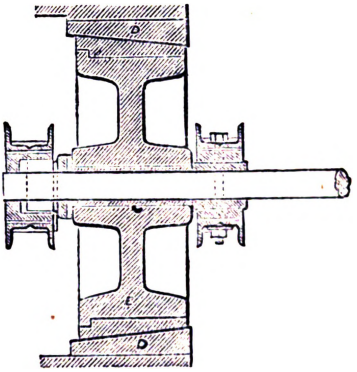

1641.

Sectional plan of accumulator.




1642.

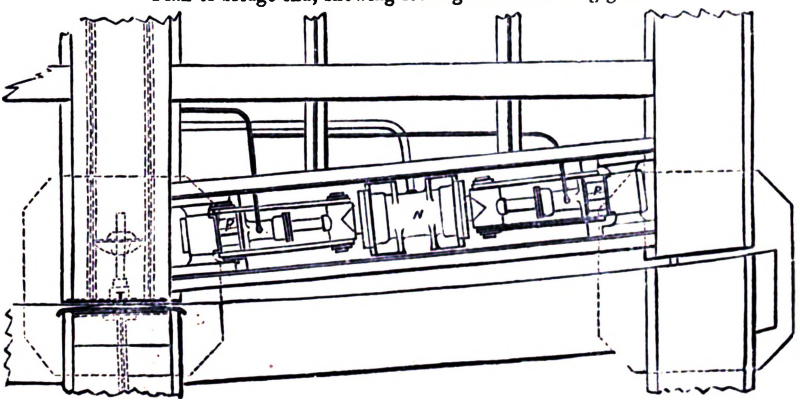
Vertical section of roller-paths and roller-frame.




1643.

*Locking-gear, &c., at ends of Bridge.*

Plan of bridge end, showing locking-bolt and lifting-gear.

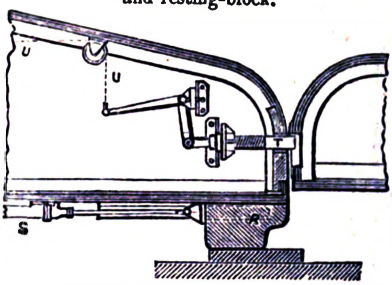


girder are pushed home by means of three separate hydraulic cylinders S S, Figs. 1645, 1646; the bridge is then let down upon these resting-blocks by the withdrawal of the toggle-joint levers P P, and the bridge ends are then perfectly solid for trains to pass over. The hydraulic cylinders N and S for working this fixing-gear at the two ends of the bridge are controlled by valves placed upon the centre platform in reach of the bridgeman, the pipes from the valves to the cylinders passing along the side of the roadway of the bridge.

For the purpose of enabling the bridgeman to stop the turning movement of the bridge at the right place, an indicator is provided consisting of a dial with two pointers which are actuated by the motion of the bridge. One of these pointers makes two revolutions and the other forty-two revolutions for one complete rotation of the bridge, they are similar to the hour and minute hands of a watch. The bridge has no stop to its turning movement, and would swing clear past its right position if the turning power were continued; but the bridgeman being guided by the indicator, knows when to stop and reverse the hydraulic engines for the purpose of stopping the bridge at its right place. When this is done, a strong locking-bolt T, Figs. 1643 to 1645, 3 in. thick, pressed outwards by a spiral spring, is shot out at each end of the bridge into a corresponding slot in the fixed girder, so as to lock the bridge; and when the bridge is required to be opened, these two bolts are withdrawn by a wire cord U, Fig. 1645, leading to the platform on which the bridgeman is

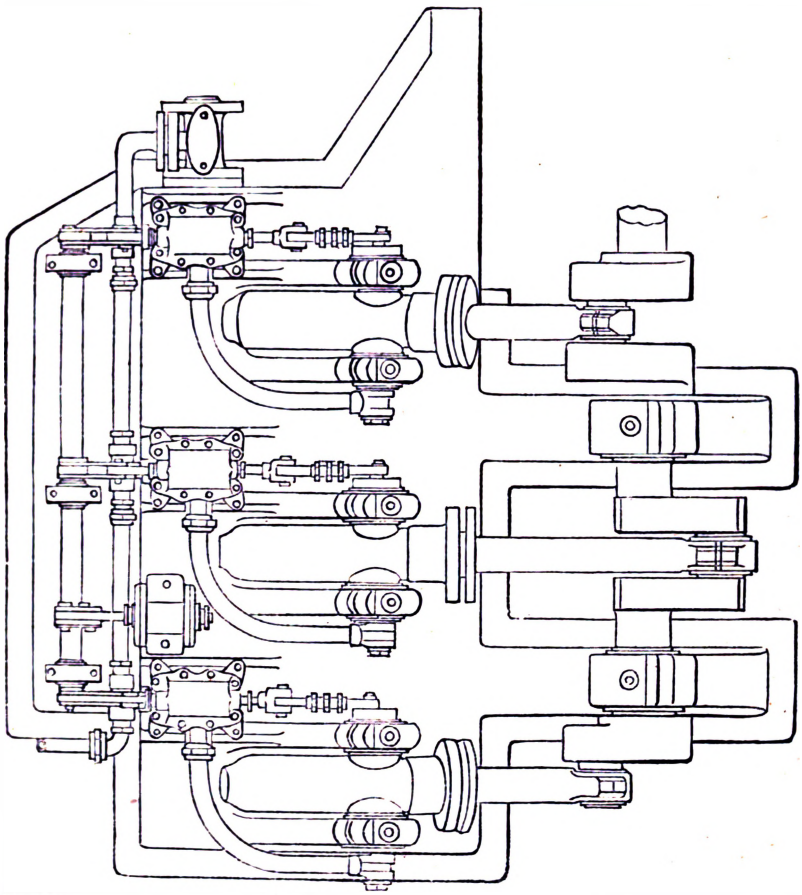
1645.

Longitudinal section showing locking-bolt and resting-block.




1647.

Plan of hydraulic engines

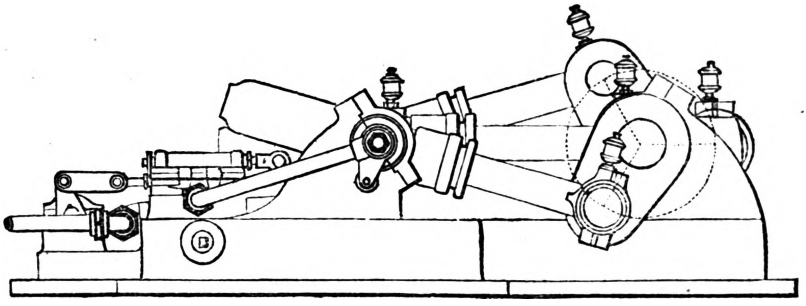


stationed. In consequence of the line of the bridge lying in a north and south direction, the heat of the sun acting alternately on the opposite sides of the bridge produces a slight lateral warping; and in order to bring the ends back into the straight line after swinging the bridge, so as to enable the two locking-bolts to enter their slots, the feet of the toggle-joint lifting-levers P P are bevelled off at 55° on their inner faces, as shown at I I in Fig. 1644, and bear against corresponding bevels V V on the bed-plates. By this means the ends of the bridge when warped are forced back into the correct centre line, in which they are then held secure by the locking-bolts.

As the accumulator is stationary in the centre pier, while the fixing-gear at the ends of the bridge travels with the bridge in swinging, the communication of water-power is effected by a central copper pipe W, Fig. 1640, passing up in the axis of the bridge through the middle of the centre girder, and having a swivel joint at the lower end. Also as the bridgeman's hand-gear rotates with the bridge while the hydraulic turning engines are stationary, the communication for working the valves is made by a central copper rod X, Fig. 1640, passing down through the

1648.

Elevation.

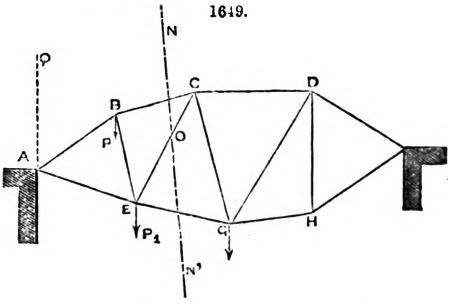


centre of the pressure-pipe W in the axis of the bridge. The hydraulic engines are reversed in either direction by the action of a small hydraulic cylinder, which is governed by the movement of a three-port valve actuated by the rod X from the bridgeman's platform.

The time required for opening or closing the bridge, including the locking of the ends, is only fifty seconds, the average speed of motion of the bridge ends being 4 ft. a second. For the purpose of ensuring safety in the working of the railway line over the bridge, a system of self-acting signals is arranged, which is actuated by the fixing-gear at the two ends of the bridge; and a signal of all right is shown by a single semaphore and lamp at each end of the fixed part of the bridge; but this cannot be shown until each one of the locking-bolts and resting-blocks is secure in its proper place.

39. *Calculation of simple Lattice-girders.—General Methods.*—The triangle is the only articulate polygon which is unyielding; in other words, a triangle composed of inflexible bars cannot yield except by the extension or the contraction of its sides under the influence of the forces applied to them. We shall give the name of *simple lattice* to a network composed of a series of triangles arranged as in Fig. 1649: the whole collection of bars being regarded as a simple figure, the strain upon all the pieces will be determined by the elementary rules of statics. The load consists of distinct weights P, $P_1$, applied to the several summits. The reaction Q of the support A is easily obtained by considering the equilibrium of the whole figure. To find the strain borne by any single piece C E, imagine a plane N N′ cutting only this piece and two others B C, E G, and seek the conditions of equilibrium of the portion of the system included between the plane N N′ and the support A. We obtain three distinct equations—two of projections, and one of moments—which determine the strains upon the three pieces crossed by N N′; for these strains appear as reactions of the right portion of the lattice upon the portion under consideration, and the other forces Q, P . . . are known.

1649.




But it is easy to avoid any elimination. If we make the secant plane pass through the point C, the strains upon the pieces B C, E C, will not appear in the equation of moments, and we shall have at once the strain upon the section E G of the side, by dividing the moment of rupture about the opposite summit C, by the perpendicular let fall from C upon E G. The strain upon B C is found in like manner, in terms of the moment of rupture taken with respect to E. Returning to the section N N′, we have only to state the equation of the vertical projections of the forces, to obtain the strain upon the bar E C in terms of the strains, already determined, of E G and B C.

If we take the upward direction of the forces as positive, the stress will be positive as long as the sum $P + P_1 + \ldots$ of the loads between A and N N′ is less than Q, and the moment of rupture will be positive if it tends to turn the figure in the same direction as Q. If we find, for example, the strain T of the bar E C positive, this will indicate that the portion C O of the bar tends to raise the portion E O, and, consequently, the piece C E is subject to a tensile strain; it will be, on the contrary, compressed, if T is negative. These conclusions would change if the bar were placed according to the other diagonal B G.

40. We may also determine the strains by a graphical process, founded upon the observation that at each summit of the triangles the strains upon the pieces which join them are in equilibrio, otherwise this summit would be displaced. Thus, beginning at the abutment, we shall decompose Q in the directions A B and A E, which will give the strains upon these two sides. Then in B we shall take the resultant of the known strain upon A B, and the weight P which is also known, and decompose it between B E and B C; this will give, without the sign, the strains upon these latter pieces. This operation must be continued for the other pieces.

41. A mixed process consists in calculating beforehand the strains upon the exterior sides or sections of flange by means of the moments of rupture, as explained in 39. Then we can at once in any summit, without passing through the preceding ones, determine graphically the strains upon the two inner bars, the function of which is to destroy the known resultant of the strains upon the two sections of flange and the particular load which may be applied to the summit in question.

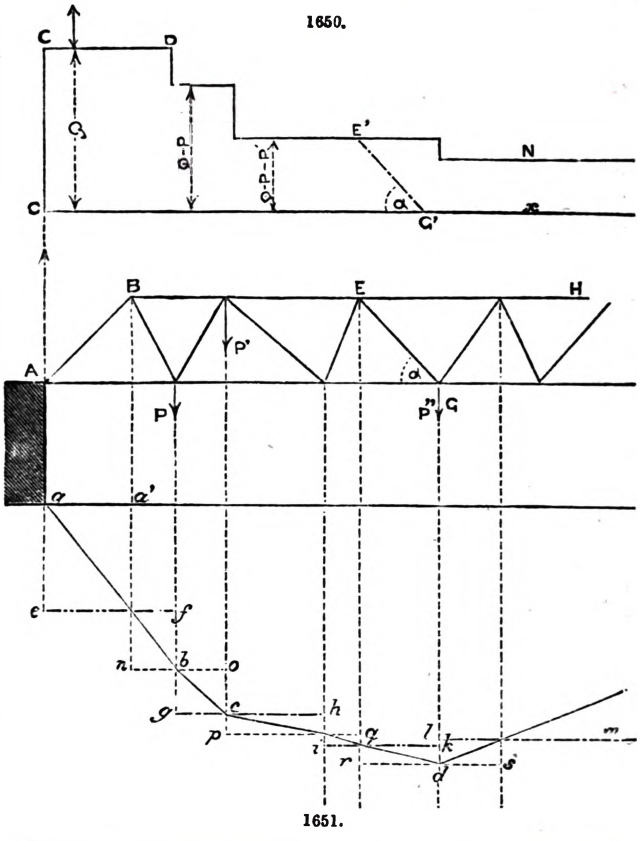
42. To pass from these general considerations to formulæ more precise, we must begin by fixing the form of the system. Let us consider the case of *straight and horizontal flanges*. On applying the foregoing process to this case, we see immediately that, to find the strain of an interior bar, it is useless to know the absolute strains upon the two sections of flange which join at one of its extremities; it is enough to find the difference of their strains; the function of the two lattice-bars being to counterbalance that one of the two sections which exerts a predominant horizontal thrust, and to support, if necessary, the load which may be applied directly to the summit under consideration.

Now, this difference of strain depends upon the increase of the moment of rupture for a given interval, or, which is the same thing, of the transverse strain. The equation of equilibrium between the vertical forces gives $\frac{F}{\sin.\ \alpha}$ for the stress upon any interior bar, $\alpha$ being the angle of this bar with the horizon, and F the stress in the interval which it occupies.

Thus, let C D N be the locus of the transverse strains, Figs. 1650, 1651, the strain upon any bar E G of the girder A B H will be represented graphically by the length of a right line E' G', parallel to E G, inscribed between the axis of the abscissæ and the horizontal line representing the stress in the interval occupied by the bar in question.

If the inclination $\alpha$ of the bars is constant, and we reduce in a constant proportion the ordinates of the locus C D N, these latter will represent directly to a given scale, either the strains or the sections of the several bars. In the absence of a special plan of strains, the locus $a\,b\,c\,d$ of the moments of rupture is sufficient to determine the strains upon the lattice-bars. For example, the stress relative to the bar E G is nothing but the tangent of inclination of the right line $c\,d$ with respect to the axis of the $x$'s, taking into account, of course, the proportion between the scales of the abscissæ and of the ordinates.

1650.




1651.

43. But the locus of the moments of rupture is specially constructed with regard to the flanges of the girder: it is a polygon the summits of which correspond with the loads P, P'. The volume or the total weight of the lower flange will be proportional to the area comprised between the axis of the $x$'s and the broken line $a\,e\,f\,g\,h\,i\,k\,l\,m$; that of the upper flange will be given by $a'\,n\,o\,p\,q\,r\,s$; and it will be seen from the figure that the whole of the two flanges will be proportional to the area $a\,b\,c\,d$ . . . of the locus of the moments of rupture.

Suppose the girder loaded with equal weights $(p + p')\,\delta$ placed at equal intervals $\delta$, and the bearing $l$ expressed by $N\,\delta$. The polygon of the moments of rupture will be parabolic, and its area will be given by the formula obtained in 6. The double of this area, multiplied by $\frac{t}{h}$, $t$ being the ratio $\frac{7800}{R} = 0{\cdot}0013$ of the weight of the cubic mètre of iron to the admitted resistance, and $h$ the height of the girder, will give for the total weight of the two flanges the value $\frac{(p + p')\,l^3\,t\,(N^2 - 1)}{6\,h\,N^2}$, say the $\frac{2\,(N^2 - 1)}{3\,N^2}$ of the weight they would have in a girder loaded in a continuous manner, if the greatest section necessary in the middle were preserved throughout the whole length.

This expression does not change whether N be even or odd. But if N be even and we substitute $2\,m$ for it, the expression becomes $\frac{(p + p')\,l^3\,t}{24\,h}\,\frac{4\,m^2 - 1}{m^2}$, whilst for N odd and equal to $2\,m + 1$, it assumes the form $\frac{2\,(p + p')\,l^3\,t}{3\,h}\,\frac{m\,(m + 1)}{(2\,m + 1)^2}$.

In practice, this weight of flange should be multiplied by a coefficient U designed to include the joint-plates and other accessories (see 63 and following sections).

In the more general case, when the extreme intervals have a length $a$ different from $\delta$, the bearing being expressed by $2a + N\delta$, the weight of the two flanges together will be

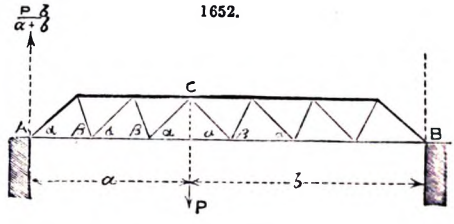
$$\frac{(p+p')\,t}{6\,h}\,(l^3 - N\,\delta^3 - 2\,a^3).$$

The total theoretical weight of the lattice-bars may also be represented by the area of a geometrical locus, namely, that having for equation $y = \frac{F\,t}{\sin.\,\alpha\cos.\,\alpha}$, the inclination $\alpha$ being liable to vary from one bar to another, as well as the stress F. But if there were vertical bars, they would elude this mode of calculation, and we should have to consider them apart.

We are now about to state the formulæ giving the maximum strains and the weight of the several parts of straight girders of regular shape. We call *struts* the bars which are compressed by a load covering all the bridge, and *braces* or *ties* those which are subject to tensile force. But it may happen that a partial load changes the direction of the strains. The struts, or at least some of them, usually require an excess of section to give them the necessary rigidity. We shall take this into account by affecting the theoretical weight with a coefficient the mean value of which is denoted by the letter V (see 68 and following sections).

44. *Girder loaded in one point only.*—The load consists of a single weight P, applied to a point C, Fig. 1652. From A to C the stress has the constant value $\frac{P\,b}{a+b}$; the struts, inclined at an angle $\alpha$, bear in this interval a constant compression $\frac{P\,b}{(a+b)\sin.\,\alpha}$, and the braces, inclined at an angle $\beta$, a tension $= \frac{P\,b}{(a+b)\sin.\,\beta}$. In the second interval, from C to B, the stress has the negative value $-\frac{P\,a}{a+b}$; the struts and braces affect, therefore, directions opposite to those which they had between A and C, and their strains are found in like manner by dividing the stress by the sine of angle of inclination.

1652.



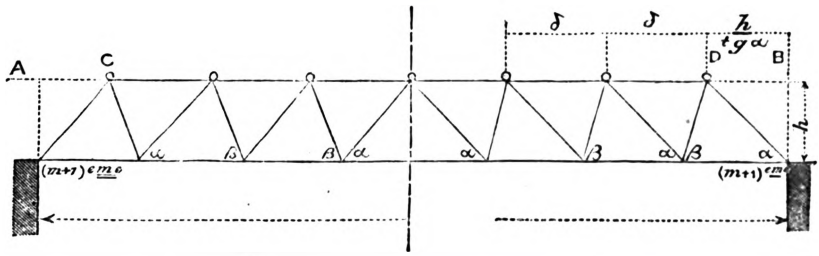

When a girder supports a single weight, economy requires that the height should be increased and that the number of triangles formed by the bars should be reduced. For example, the most economical means of supporting a weight in the middle of the bearing consists theoretically of two bars at 45° resting against each other at their summits, and having their lower extremities supported upon abutments and held by a tie.

If the single weight P is a moving one, the maximum strain upon the bars having the same inclination will vary uniformly according to the same law as the maximum whole stress, which reaches the value P towards the support, and is reduced to $\frac{1}{2}$ P in the middle.

45. *Girders uniformly loaded on the upper side.*—If the load rests directly upon the upper flange, the several sections of the latter will undergo slight partial deflections; but these may be neglected when we regard the load as distributed among the upper summits proportionally to the intervals. This load is of two kinds: one portion denoted by $p$ per lineal mètre remains permanently throughout the bearing; the other portion, $p'$ per mètre, is moving, that is, it may affect either the whole bearing or only any portion of it; the letter $q$ denotes the ratio $\frac{p'}{p+p'}$. Always supposing that the loaded points are equidistant, we shall consider various particular figures, symmetrical with respect to the middle of the bearing.

First arrangement, Fig. 1653. The intermediate upper summits support each a weight $p\,\delta$, and

1653.




accidentally another weight $p'\,\delta$; but in the two extreme summits C and D, these weights are reduced to $\frac{p}{2}\left(\delta + \frac{h}{\tan.\,\alpha}\right)$ and $\frac{p'}{2}\left(\delta + \frac{h}{\tan.\,\alpha}\right)$.

According to 5, the stress will reach its maximum when the load extends over a portion of the bridge only, and we easily find the following expressions. The several pieces are numbered from the middle to each abutment, for any two symmetrical pieces are in perfectly identical conditions.

A lengthening A C, D B, of the flanges, with upright stays at the ends, will be found useful in practice for a load above; but the formulæ do not include this, unless, indeed, it be included in the coefficient U.

Any strut, the order of which with respect to the others is expressed by $n$, supports the following maximum strain of compression:

$$(2n-1)\frac{p\delta}{2\sin.\alpha}+\frac{p'}{4\sin.\alpha\left(m\delta+\frac{h}{\tan.\alpha}\right)}\left\{(m+n)(m+n-1)\delta^2+\left[\frac{h}{\tan.\alpha}+(2m+2n-1\delta')\right]\frac{h}{\tan.\alpha}\right\},$$

except the end strut, the order of which is $m+1$, and which will support only

$$\frac{(p+p')}{\sin.\alpha}\left(m\delta+\frac{h}{2\tan.\alpha}\right).$$

As to the braces, the tension of the $n$th reckoning from the middle is given without exception by

$$2n-1\frac{p\delta}{2\sin.\beta}+\frac{p'}{4\sin.\beta\left(m\delta+\frac{h}{\tan.\alpha}\right)}\left\{(m+n)(m+n-1)\delta^2+\left[\frac{h}{\tan.\alpha}+(2m+2n-1)\delta\right]\frac{h}{\tan.\alpha}\right\}.$$

The flanges require a full load to produce in them the maximum strain. The compression of the $n$th upper section is $\frac{(p+p'h)}{2\tan.^2\alpha}+\frac{(p+p')\delta}{\tan.\alpha}\left(m-n+\frac{1}{2}\right)+\frac{(p+p')\delta^2}{2h}[m^2-(n-1)^2]$; which gives for the first which is the most heavily loaded $\frac{p+p'}{2}\left[\frac{h}{\tan.^2\alpha}+\frac{(2m-1)\delta}{\tan.\alpha}+\frac{m^2\delta^2}{h}\right]$.

Tension of the $n$th lower section $=\frac{p+p'}{\tan.\alpha}\left(m\delta+\frac{h}{2\tan.\alpha}\right)+\frac{(p+p')\delta^2}{2h}[m^2-(n-1)^2]$; say for the first, $\frac{p+p'}{2}\left[\frac{h}{\tan.^2\alpha}+\frac{2m\delta}{\tan.\alpha}+\frac{m^2\delta^2}{h}\right]$.

Multiplying the strain upon a strut by its length and by the quantity $t$ V, we shall have its weight. Then, summing the expression obtained, in which $n$ takes the successive values 1, 2, 3, . . . $m$, doubling the result, and adding the two extreme struts (the order of which is $m+1$) calculated apart, we find: Total weight of the $2(m+1)$ struts

$$=\frac{p\,h\,t\,\mathrm{V}}{\sin.^2\alpha}\left[m(m+2)\delta+\frac{h}{\tan.\alpha}\right]+\frac{m\,p'\,h\,t\,\mathrm{V}}{2\sin.^2\alpha\left(m\delta+\frac{h}{\tan.\alpha}\right)}$$

$$\left\{\frac{\delta^2}{3}(7m^2+12m-1)+\frac{h}{\tan.\alpha}\left[\frac{(m+2)h}{m\tan.\alpha}+3(m+2)\delta\right]\right\}.$$

We have next, without a coefficient of stiffness: Total weight of the $2m$ braces

$$=\frac{m^2p\delta\,h\,t}{\sin.^2\beta}+\frac{m\,p'\,h\,t}{2\sin.^2\beta\left(m\delta+\frac{h}{\tan.\alpha}\right)}\left[\frac{\delta^2}{3}(7m^2-1)+\frac{h}{\tan.\alpha}\left(\frac{h}{\tan.\alpha}+3m\delta\right)\right];$$

Then with coefficient U, for joint-plates, and so on:

Total weight of the upper flange $=m(p+p')\delta\,t\,\mathrm{U}\left[\frac{h}{\tan.^2\alpha}+\frac{m\delta}{\tan.\alpha}+\frac{\delta^2}{6h}(4m-1)(m+1)\right]$;

Total weight of the lower flange

$$=\frac{(p+p')h^2\,t\,\mathrm{U}}{\tan.^3\alpha}+m(p+p')\delta\,t\,\mathrm{U}\left[\frac{3h}{\tan.^2\alpha}+\frac{3m\delta}{\tan.\alpha}+\frac{\delta^2}{6h}(4m+1)(m-1)\right];$$

Total weight of the two flanges together $=\frac{(p+p')\,t\,\mathrm{U}}{3}\left(\frac{l^3}{2h}-\frac{m\delta^3}{h}-\frac{h^2}{\tan.^3\alpha}\right)$.

This last result may be obtained directly by means of the area of the locus of the moments of rupture (see end of 6).

46. Particular case $\alpha=\beta$, and consequently $\frac{h}{\tan.\alpha}=\frac{\delta}{2}$, and the bearing $l=(2m+1)\delta$.

Strain upon the $n$th strut or the $n$th brace $=\frac{(2n-1)\,p\,\delta}{2\sin.\alpha}+\frac{p'\delta[4(m+n)^2-1]}{8(2m+1)\sin.\alpha}$;

Except the extreme strut, of order $m+1$, which supports $\frac{(p+p')\delta}{\sin.\alpha}\left(m+\frac{1}{4}\right)$;

Compression of the $n$th end of upper flange $=\frac{(p+p')\delta^2}{2h}\left(m^2-n^2+m+n-\frac{1}{4}\right)$;

Maximum strain of upper flange $=\frac{(p+p')\delta^2}{2h}\left(m^2+m-\frac{1}{4}\right)$;

Tension of the $n$th and of lower flange $=\frac{(p+p')\delta^2}{2h}\left(m^2-n^2+m+n-\frac{1}{4}\right)$;

Maximum strain upon lower flange $= \frac{(p+p')\delta^2}{2h}\left(m^2+m+\frac{1}{4}\right)$.

Total weight of the $2(m+1)$ struts $= \frac{p\,h\,\delta\,t\,V}{\sin.^2\alpha}\left(m^2+2m+\frac{1}{2}\right)+\frac{p'\,\delta\,h\,t\,V\,(28m^2+18m-1)}{12\sin.^2\alpha\,(2m+1)}$;

Total weight of the $2m$ braces $= \frac{m^2 p\,h\,\delta\,t}{\sin.^2\alpha}+\frac{m p'\,h\,\delta\,t\,(28m^2+18m-1)}{12\sin.^2\alpha\,(2m+1)}$.

If we substitute for the coefficient V, with which the struts alone are affected, a coefficient $\frac{1+V}{2}$ applied to the whole of the lattice, we shall have:

Total weight of the lattice $= \frac{(2m+1)^2(p+p')\,\delta\,h\,t\,(1+V)}{4\sin.^2\alpha}\left[1+\frac{m(4m^2+6m-1)}{3(2m+1)^3}q\right]$.

And for the flanges, we have:

Weight of the upper flange $= \frac{m(p+p')\,\delta^3\,t\,U}{12h}(8m^2+12m+1)$;

Weight of the lower flange $= \frac{(p+p')\,\delta^3\,t\,U}{12h}\left(8m^3+12m^2+7m+\frac{3}{2}\right)$;

Weight of the two flanges together $= \frac{(p+p')\,\delta^3\,t\,U}{6h}\left(8m^3+12m^2+4m+\frac{3}{4}\right)$.

If $\alpha$ were of 45°, we should substitute $\frac{1}{\sqrt{2}}$ for sin. $\alpha$, and $2h$ for $\delta$; we might, besides, substitute for $m$ the value $\frac{\epsilon-2h}{4h}$.

47. Another particular case: $\beta = 90°$. We have sin. $\beta = 1$, $\frac{h}{\tan.\alpha} = \delta$; the bearing becomes $2(m+1)\delta$, say $2m'\delta$, making $m = m'-1$. In the following values, $\frac{h}{\sqrt{h^2-\delta^2}}$ may be substituted for sin. $\alpha$.

Strain upon the $n$th strut (including the last, of order $m'$)

$$= \frac{(2n-1)\,p\,\delta}{2\sin.\alpha}+\frac{(m'+n)(m'+n-1)}{4m'\sin.\alpha}p'\delta;$$

Strain upon the $n$th brace $= \frac{(2n-1)\,p\,o}{2}+\frac{(m'+n)(m'+n-1)\,p\,\delta}{4m}$;

Strain upon the $n$th end of the upper flange $= \frac{(p+p')\,\delta^2}{2h}(m'^2-n^2)$;

Maximum strain upon the upper flange $= \frac{(p+p')\,\delta^2}{2h}(m'^2-1)$;

Maximum strain upon the $n$th end of lower flange $= \frac{(p+p')\,\delta^2}{2h}(m'+n-1)(m'-n+1)$;

Maximum strain upon the lower flange $= m'^2\frac{(p+p')\,\delta^2}{2h} = \frac{(p+p')\,l^2}{8h}$;

Total weight of the $2m'$ struts $= \frac{h\,\delta\,t\,V}{\sin.^2\alpha}\left[m'^2 p+\frac{7m'^2-1}{6}p'\right]$;

Total weight of the $2(m'-1)$ braces $= (m'-1)\,\delta\,h\,t\left[(m'-1)\,p+\frac{7m'-5}{6}p'\right]$;

Total weight of the upper flange $= \frac{m'(m'-1)(4m'+1)(p+p')\,\delta^3\,t\,U}{6h}$;

Total weight of the lower flange $= m'(m'+1)(4m'-1)\frac{(p+p')\,\delta^3\,t\,U}{6}$;

Total weight of the two flanges together $= m'(4m'^2-1)\frac{(p+p')\,\delta^3\,t\,U}{3h}$.

48. In the particular case $\alpha = 90°$, the two middle struts will become one. For $l$ and $\delta$ constant, this case will be a little less economical than the preceding.

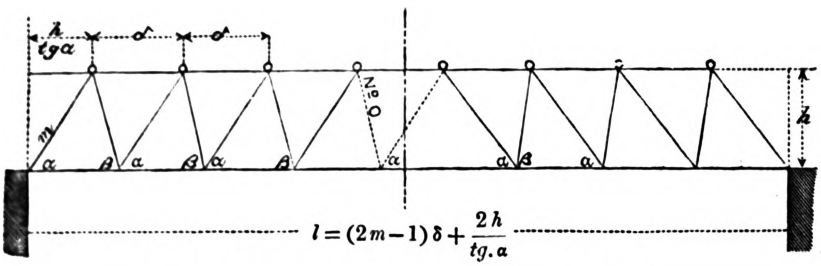
49. Second arrangement, Fig. 1654. This arrangement differs from the preceding only in the fact that the loaded point falls in the middle of the girder. The dotted triangle in the middle resists only beneath the action of a partial load; it offers a defect of symmetry if $\alpha$ is not equal to $\beta$. The weights applied to the extreme summits are inferior to the others, as in the preceding arrangements (see 45).

Strain upon the $n$th strut

$$= \frac{p\,n\,\delta}{\sin.\alpha}+\frac{p'}{2\sin.\alpha\left(2m\delta-\delta+\frac{2h}{\tan.\alpha}\right)}\left\{\delta^2(m+n)(m+n-1)+\frac{h}{\tan.\alpha}\left[\frac{h}{\tan.\alpha}+\delta(2m+2n-1)\right]\right\};$$

Except the last (the $m$th), which supports $\frac{p+p'}{\sin.\alpha}\left[(2m-1)\,\delta+\frac{h}{\tan.\alpha}\right]$;

1654.




Strain upon the $n$th brace

$$= \frac{p\,n\,\delta}{\sin.\beta} + \frac{p'}{2\sin.\beta\left(2m\delta - \delta + \frac{2h}{\tan.\alpha}\right)}\left\{\delta^2(m+n)(m-n-1) + \frac{h}{\tan.\alpha}\left[\frac{h}{\tan.\alpha} + \delta(2m+2n-1)\right]\right\}$$

Strain upon the $n$th section of the upper flange

$$= (m-n+1)(m+n-2)\frac{(p+p')\delta^2}{2h} + \frac{p+p'}{2\tan.\alpha}\left[\delta(2m-2n+1) + \frac{h}{\tan.\alpha}\right];$$

Which gives for the middle section, the most heavily loaded,

$$\frac{m(m-1)(p+p')\delta^2}{2h} + \frac{p+p'}{2\tan.\alpha}\left[(2m-1)\delta + \frac{h}{\tan.\alpha}\right];$$

Strain upon the $n$th section of the lower flange

$$= (m+n-1)(m-n)\frac{(p+p')\delta^2}{2h} + \frac{p+p'}{2\tan.\alpha}\left[(2m-1)\delta + \frac{h}{\tan.\alpha}\right];$$

Which gives in the middle the same maximum strain as in the upper flange.

Total weight of the $2m+1$ struts, inclined at an angle $\alpha$,

$$= \frac{p\,h\,t\,V}{\sin.^2\alpha}\left[\frac{h}{\tan.\alpha} + \delta(m^2+m-1)\right] + \frac{p'\,h\,t\,V}{6\sin.^2\alpha\left(2m\delta - \delta + \frac{2h}{\tan.\alpha}\right)}$$

$$\left\{\delta^2(14m^3+3m^2-17m+6) + \frac{3h}{\tan.\alpha}\left[\frac{(2m+3)h}{\tan.\alpha} + \delta(6m^2+6m-5)\right]\right\}$$

Total weight of the $2m-1$ braces, inclined at an angle $\beta$,

$$= \frac{m(m-1)p\,\delta\,h\,t}{\sin.^2\beta} + \frac{p'\,h\,t}{6\sin.^2\beta\left(2m\delta - \delta + \frac{2h}{\tan.\alpha}\right)}$$

$$\left\{\delta^2(14m^3-21m^2+7m) + \frac{3h}{\tan.\alpha}\left[\frac{(2m-1)h}{\tan.\alpha} + \delta(6m^2-6m+1)\right]\right\};$$

Total weight of the upper flange

$$= m(4m+1)(m-1)\frac{(p+p')\delta^3\,t\,U}{6h} + \left[\frac{(2m-1)h}{2\tan.\alpha} + \left(m^2-m+\frac{1}{2}\right)\delta\right]\frac{(p+p')\delta\,t\,U}{\tan.\alpha};$$

Total weight of the lower flange

$$= m(m-1)(4m-5)\frac{(p+p')\delta^3\,t\,U}{6h} + \left[\frac{3(2m-1)h}{2\tan.\alpha} + \left(3m^2-3m+\frac{1}{2}\right)\delta\right]$$
$$\frac{(p+p')\delta\,t\,U}{\tan.\alpha} + \frac{(p+p')h^2\,t\,U}{\tan.^3\alpha};$$

Total weight of the two flanges together

$$= (2m-1)(p+p')\delta\,t\,U\left[\frac{2m(m-1)\delta^2}{3h} - \frac{l}{\tan.\alpha}\right] + \frac{(p+p')h^2\,t\,U}{\tan.^3\alpha}.$$

50. Particular case $\alpha = \beta$, and consequently $\frac{h}{\tan.\alpha} = \frac{\delta}{2}$. The bearing is then $2m\delta$.

Strain upon the $n$th strut $= \frac{p\,n\,\delta}{\sin.\alpha} + \frac{p'\delta}{4m\sin.\alpha}\left[(m+n)^2 - \frac{1}{4}\right]$

Except the last ($m$th), which supports $(p+p')\frac{(4m-1)\delta}{4\sin.\alpha}$;

Strain upon the $n$th brace $= \frac{p\,n\,\delta}{\sin.\alpha} + \frac{p'\delta}{4m\sin.\alpha}\left[(m+n)^2 - \frac{1}{4}\right]$;

Strain upon the $n$th section of the upper flange $= \left(m^2 - n^2 + 2n - \frac{5}{4}\right)\frac{(p+p')\delta^2}{2h}$;

Strain upon the $n$th section of the lower flange $= \left(m^2 - n^2 + n - \frac{1}{4}\right) \frac{(p+p')\,\delta^2}{2h}$;

Maximum strain in the middle of the flanges $= \left(m^2 - \frac{1}{4}\right) \frac{(p+p')\,\delta^2}{2h}$;

Total weight of the $2m+1$ struts (including one side of the middle triangle)

$$= \frac{(2m^2+2m-1)\,p\,\delta\,h\,t\,V}{2\sin.^2\alpha} + \frac{(56m^3+48m^2-26m+3)\,p'\,\delta\,h\,t\,V}{48m\sin.^2\alpha};$$

Total weight of the $2m-1$ braces (including one side of the middle triangle)

$$= \frac{m(m-1)\,p\,\delta\,h\,t}{\sin.^2\alpha} + \frac{(56m^2-48m^2-2m+3)\,p'\,\delta\,h\,t}{48m\sin.^2\alpha};$$

Total weight of the whole lattice, applying the coefficient $\frac{1+V}{2}$,

$$= \frac{(4m^2-1)\,(p+p')\,\delta\,h\,t\,(1+V)}{4\sin.^2\alpha}\left[1 + \frac{8m^3-2m+3}{12m\,(4m^2-1)}\,q\right];$$

Total weight of the upper flange $= (16m^3 - 10m + 3)\,\frac{(p+p')\,\delta^3\,t\,U}{24h}$;

Total weight of the lower flange $= m\,(8m^2+1)\,\frac{(p+p')\,\delta^3\,t\,U}{12h}$;

Total weight of the two flanges together $= (32m^3 - 8m + 3)\,\frac{(p+p')\,\delta^3\,t\,U}{24h}$.

The weight of the lower flange exceeds by $\frac{(4m^2-1)\,(p+p')\,\delta^3\,t\,U}{8h}$ that of the upper flange.

If the inclination of the bars is 45°, the value of the strains upon them will be

$$h\sqrt{2}\left[2pn + \frac{p'}{2m}\left(m+n+\frac{1}{2}\right)\left(m+n-\frac{1}{2}\right)\right],$$

with the exception of the last or $n$th strut, which will support $\left(2m - \frac{1}{2}\right)(p+p')\,h\sqrt{2}$. The total weight of the lattice is $= (4m^2-1)\,(p+p')\,h^2\,t\,(1+V)\left[1 + \frac{8m^3-2m+3}{12m\,(4m^2-1)}\,q\right]$. In the strains upon the flanges $\frac{\delta^2}{2h}$ should be changed into $2h$, and in their weight $\frac{\delta^3}{h}$ into $8h^2$. And in all the expressions the quantity $\frac{l}{4h}$ may be substituted for $m$.

51. The particular case $\beta = 90°$, will offer a defect of symmetry in the middle, like the general case. The bearing $l$ becomes $(2m+1)\,\delta$.

The strain upon the $n$th vertical brace is $p\,n\,\delta + p'\,\delta\,\frac{(m+n)\,(m+n+1)}{2\,(2m+1)}$, and that of the $n$th strut is given by the same formula divided by sin. $\alpha$.

The $n$th section of the upper or the lower flange supports

$$(m+n)\,(m-n+1)\,(p+p')\,\frac{\delta^2}{2h}.$$

Total weight of the $2m+1$ struts $= \frac{m\,(m+1)\,\delta\,h\,t\,V}{\sin.^2\alpha}\left(p + \frac{7}{6}\,p'\right)$;

Total weight of the $2m-1$ braces $= m\,\delta\,h\,t\left((m-1)\,p + \frac{7m-5}{6}\,p'\right)$;

Total weight of the upper flange $= m\,(m+1)\,(4m-1)\,(p+p')\,\frac{\delta^3\,t\,U}{6h}$;

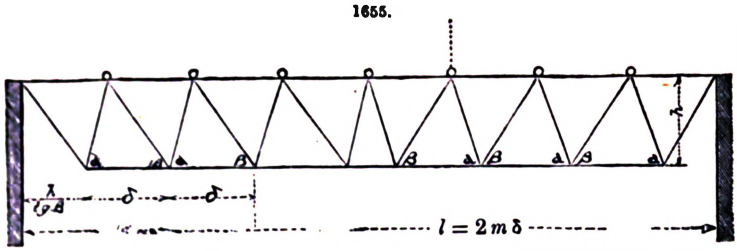
Total weight of the lower flange $= m\,(m+1)\,(4m+5)\,(p+p')\,\frac{\delta^3\,t\,U}{6h}$;

Total weight of the two flanges together $= \frac{2}{3}\,m\,(m+1)\,(2m+1)\,(p+p')\,\frac{\delta^3\,t\,U}{h}$.

52. Third arrangement, Fig. 1655. This arrangement differs from the first, in the fact of the struts being equal in number to the braces, which will simplify the formulæ. As the girder ends with a brace, it may be supported on the ends of the upper flange, as shown in the figure.

The weights applied to the upper summits are all equal to $p\,\delta$ for the permanent portion, and to $p'\,\delta$ for the moving load. The maximum reaction of the abutment, not including the weight which it bears directly has the value $\left(m - \frac{1}{2}\right)(p+p')\,\delta$.

1655.




Strain upon any $n$th strut $= \frac{\delta}{2 \sin. \alpha} \left[ (2n-1)\, p + (m+n)(m+n-1) \frac{p'}{2m} \right]$;

Strain upon the $n$th brace $= \frac{\delta}{2 \sin. \beta} \left[ (2n-1)\, p + (m+n)(m+n-1) \frac{p'}{2m} \right]$;

Strain upon the $n$th section of the upper flange $= \frac{(p+p')\,\delta}{2} \left[ (m^2 - n^2) \frac{\delta}{h} + \frac{(2n-1)}{\tan. \beta} \right]$;

Which gives for the first towards the middle, $\frac{(p+p')\,\delta}{2} \left[ (m^2 - 1) \frac{\delta}{h} + \frac{1}{\tan. \beta} \right]$;

Strain upon the $n$th section of the lower flange $= (m-n+1)(m+n-1)(p+p') \frac{\delta^2}{2h}$;

Which gives for the maximum strain in the middle, $\frac{m^2 (p+p')\,\delta^2}{2h}$, or $\frac{(p+p')\,l^2}{8h}$;

Total weight of the $2m$ struts $= \frac{\delta h t V}{\sin.^2 \alpha} \left[ m^2 p + \frac{7m^2 - 1}{6} p' \right]$;

Total weight of the $2m$ braces $= \frac{\delta h t}{\sin.^2 \beta} \left( m^2 p + \frac{7m^2 - 1}{6} p' \right)$;

Total weight of the upper flange $= m (p+p') \delta^2 \left[ \frac{(4m+1)(m-1)\,\delta}{6h} + \frac{m}{\tan. \beta} \right] t U$;

Total weight of the lower flange $= m (p+p') \delta^2 \left[ \frac{(4m-1)(m+1)\,\delta}{6h} - \frac{m}{\tan. \beta} \right] t U$;

Total weight of the two flanges together $= m (4m^2 - 1)(p+p') \frac{\delta^2 t U}{3h}$.

The difference between the weights of the upper and lower flanges is expressed by $m^2 (p+p') \delta^2 t U \left( \frac{2}{\tan. \beta} - \frac{\delta}{h} \right)$.

53. Particular case in which $\alpha = \beta$. The quantity $\frac{h}{\tan. \beta}$ becomes $\frac{\delta}{2}$.

Strain upon the $n$th struts and braces $= \frac{\delta}{2 \sin. \alpha} \left[ (2n-1)\, p + (m+n)(m+n-1) \frac{p'}{2m} \right]$;

Strain upon the $n$th section of the upper flange $= \left( m^2 - n^2 + n - \frac{1}{2} \right) (p+p') \frac{\delta^2}{2h}$;

Strain upon the $n$th section of the lower flange $= (m-n+1)(m+n-1)(p+p') \frac{\delta^2}{2h}$;

Total weight of the $2m$ braces $= (p+p') \frac{m^2 \delta h t}{\sin.^2 \alpha} \left( 1 + \frac{m^2 - 1}{6m^2} q \right)$;

Total weight of the $2m$ struts = the preceding expression multiplied by V;

Volume of the upper flange = volume of the lower $= m (4m^2 - 1)(p+p') \frac{\delta^3 t U}{6h}$.

If the inclination of the bars is 45°, the strains upon them will be calculated by the formula $h \sqrt{2} \left[ (2n-1)\, p + (m+n)(m+n-1) \frac{p'}{2m} \right]$, and their total weight, struts and braces together, by $4m^2 (p+p') h^2 t (1+V) \left( 1 + \frac{m^2 - 1}{6m^2} q \right)$.

The total weight of the two flanges will be $8m (4m^2 - 1)(p+p') \frac{h^2 t U}{3}$, and in the expression of their strains $\frac{\delta^2}{2h}$ should be changed into $2h$. We may also substitute $\frac{l}{4h}$ for $m$.

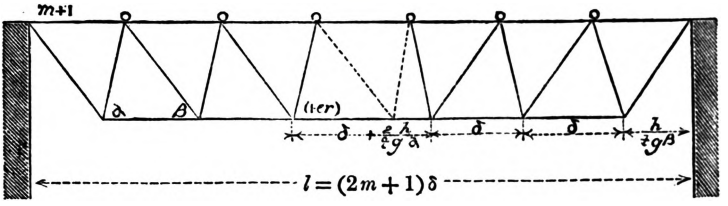
54. Particular case in which $\beta = 90°$. The strain upon the extreme ends of the upper flange is rendered nul, and the extreme braces are simple suspension-rods, necessary only on the hypothesis that the point of support upon the abutments is taken at the height of the upper

flange. But if these suspension-rods be suppressed and the girder supported by the bottom, we shall have exactly the case in 47. Our present formulæ would give $\delta h t \left(m^2 p + \frac{7m^2-1}{6} p'\right)$ as the total weight of the braces, including the suspension-rods; but the suppression of these latter will reduce the weight to $(m-1)^2 \delta h t \left(p + \frac{7m-5}{6(m+1)} p'\right)$, as in the section above referred to.

In the case in which $\alpha = 90°$, the two struts in the middle become one. The hypotheses $\alpha = 90°$ or $\beta = 90°$, introduced into the general formulæ of 52, both give the same total weight for the flanges and for the lattice.

55. Fourth arrangement, Fig. 1656. This figure differs from the preceding, in the fact that the middle of the girder does not coincide with one of the loaded points, but falls in the middle

1656.




of an interval. The dotted triangle, in the middle, offers a defect of symmetry, if $\alpha$ differs from $\beta$; it does not resist when the load extends throughout the length; one of the bars which compose it is regarded as a strut, the other as a brace.

Strain upon the $n$th strut $= \frac{\delta}{\sin.\alpha}\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)} p'\right]$;

Strain upon the $n$th brace $= \frac{\delta}{\sin.\beta}\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)} p'\right]$;

Strain upon the $n$th upper horizontal section

$$= (m-n+1)(m+n)(p+p')\frac{\delta^2}{2h} + (n-1)(p+p')\frac{\delta}{\tan.\beta};$$

Strain upon the $n$th lower horizontal section $= (m-n+)(m+n)(p+p')\frac{\delta^2}{2h}$;

Maximum strain in the middle of the flanges $= m(m+1)(p+p')\frac{\delta^2}{2h}$;

Total weight of the $2m+1$ struts $= \frac{m(m+1)\delta h t \mathrm{V}}{\sin.^2\alpha}\left(p + \frac{7}{6}\right)$;

Total weight of the $2m+1$ braces $= \frac{m(m+1)\delta h t}{\sin.^2\beta}\left(p + \frac{7}{6}p'\right)$;

Total weight of the upper flange $= m(m+1)(p+p')\delta^2 t \mathrm{U}\left[\frac{(4m-1)\delta}{6h} + \frac{1}{\tan.\beta}\right]$;

Total weight of the lower flange $= m(m+1)(p+p')\delta^2 t \mathrm{U}\left[\frac{(4m+5)\delta}{6h} - \frac{1}{\tan.\beta}\right]$;

Total weight of the two flanges together $= \frac{2}{3} m(m+1)(2m+1)(p+p')\frac{\delta^3 t \mathrm{U}}{h}$.

56. Case in which $\alpha = \beta$.

Strain upon the lattice-bars $= \frac{\delta}{\sin.\alpha}\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)} p'\right]$;

Strain upon the $n$th upper horizontal section $= (m^2 - n^2 + m + 2n - 1)(p+p')\frac{\delta^2}{2h}$;

Strain upon the lower horizontal section $= (m+n)(m-n+1)(p+p')\frac{\delta^2}{2h}$;

Total weight of the lattice $= \frac{m(m+1)\delta h t (1+\mathrm{V})}{\sin.^2\alpha}\left(p + \frac{7}{6}p'\right)$;

Total weight of the upper flange = weight of the lower flange

$$= m(m+1)(2m+1)(p+p')\frac{\delta^3 t \mathrm{U}}{3h}.$$

If the inclination is 45°, $\frac{1}{\sqrt{2}}$ may be substituted for sin. $\alpha$, and $2h$ for $\delta$. The quantity $m$ is then equal to $\frac{l}{4h} - \frac{1}{2}$.

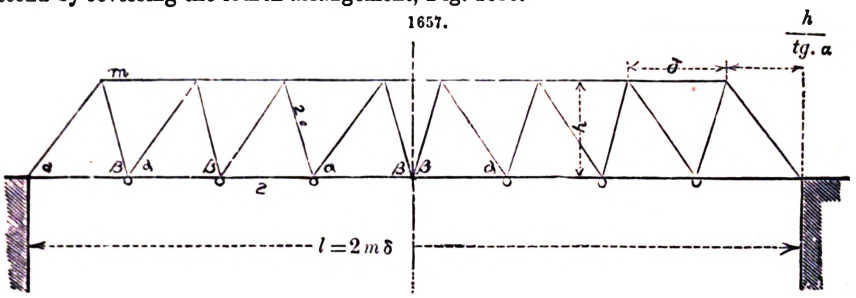
57. The case in which $\beta = 90°$ is similar to the corresponding case of the second arrangement in 51. There will be nothing changed except the total weight of the braces, which will amount

here to $m\,(m+1)\,\delta\,h\,t\left(p+\frac{7}{6}\,p'\right)$, on account of their number being $2\,m$ instead of $2\,(m-1)$, the extreme braces serving only to suspend the girder from the upper points of support.

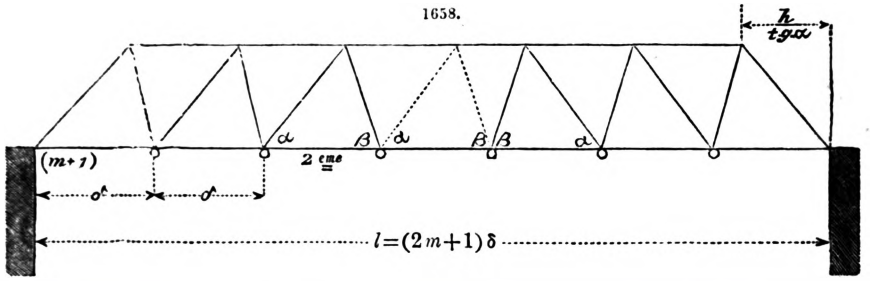
58. *Girders uniformly loaded on the lower side.*—If we turn upside down the various systems which we have been examining, the load will be transposed to the lower side, and we shall have merely to apply the same formulæ with the signs of the strains changed; the lower flange will have become the upper, the struts braces, and *vice versâ*. We must also change $\alpha$ into $\beta$, and $\beta$ into $\alpha$, the symbol $\alpha$ being always applied to struts and $\beta$ to braces.

We shall consider only the two arrangements shown in Figs. 1657 and 1658. The first is obtained by reversing the third arrangement of girders loaded on the upper side, Fig. 1655, and the second by reversing the fourth arrangement, Fig. 1656.

1657.




1658.




The formulæ applicable to these two arrangements and to their particular cases will be found in Table VIII.

59. *Inclination of the Lattice-bars.*—When the inclination $\alpha$ of the bars is quite arbitrary, it should be taken equal to 45°, for a bar crossing an interval $\delta$, will weigh $\frac{F\,t\,\delta_1}{\sin.\,\alpha\cos.\,\alpha}$, which amounts to $\frac{F\,t}{\sin.\,\alpha\cos.\,\alpha}$ the lineal mètre of girder: now this expression is a minimum when $\alpha = 45°$.

But simple lattice-girders are usually divided into intervals of a given length $\delta$, which form the base of triangles the other sides of which are a strut inclined to an angle $\alpha$ and a brace inclined to $\beta$, so that these two angles $\alpha$ and $\beta$ are an implicit function one of the other, for they are connected by the relation $h\,(\cot.\,\alpha+\cot.\,\beta)=\delta$, whence $\frac{d\beta}{d\alpha}=-\frac{\sin.^2\beta}{\sin.^2\alpha}$, $\delta$ and $h$ being regarded as given constants. The weight of the two bars of one of the triangles has the value $F\,h\,t\left(\frac{V}{\sin.^2\alpha}+\frac{1}{\sin.^2\beta}\right)$, and it becomes a minimum when we have $\frac{V\cos.\,\alpha}{\sin.^3\alpha}+\frac{\cos.\,\beta}{\sin.^3\beta}\cdot\frac{d\beta}{d\alpha}=0$, whence $\frac{\tan.\,\alpha}{\tan.\,\beta}=V$. It would, therefore, be necessary to give the struts an inclination nearer the vertical than the braces.

60. It is easy to solve the question from a more general point of view, by attributing distinct coefficients to each of the two flanges and to each of the two systems of bars, as if, for example, these different parts were made of different materials. On this hypothesis let $\xi$ denote, for the upper flange, the value of the lineal mètre of a prism capable of bearing a net strain of 1 kilogramme, taking into account the joint-plates and other accessories. Let $\xi_1$, $\xi'$, and $\xi''$ be the analogous quantities relative to the lower flange, the struts, and the braces. And let us take, by way of example, a girder loaded on the lower side of the system of Fig. 1657, in which $l$ is expressed by $2\,m\,\delta$.

The total value P of the girder will be given by the formulæ of weights of Table VIII., by suppressing the factor $t$ and the coefficients U V, and substituting for them the new coefficients $\xi$, and so on. If we put

$$\left(1+\frac{m^2-1}{6\,m^2}\,q\right)\xi'=a,\ \left(1+\frac{m^2-1}{6\,m^2}\,q\right)\xi''=a',\ \frac{4\,m^2-1}{6\,m}\,(\xi+\xi_1)+\frac{1}{2}\,(\xi_1-\xi)=c,$$

and $\frac{4\,m^2-1}{6\,m}\,(\xi+\xi_1)-\frac{1}{2}\,(\xi_1-\xi)=c'$, and substitute the value $\frac{\delta}{\cot.\,\alpha+\cot.\,\beta}$ for $h$, and $\frac{l}{2\,m}$ for $\delta$, we shall have $P=\frac{1}{4}\,(p+p')\,l^2\left\{\frac{1}{\cot.\,\alpha+\cot.\,\beta}\left(\frac{a}{\sin.^2\alpha}+\frac{a'}{\sin.^2\beta}\right)+c\cot.\,\alpha+c'\cot.\,\beta\right\}+\Omega;$

$\Omega$ is the additional term intended to include accessory pieces, such as gussets, and so on, regarded as independent of $h$, as well as of the angles $\alpha$ and $\beta$. The quantities $a$, $a'$, $c$, $c'$, are also constants, for $\delta$, and consequently $m$, is given; the height $h$ is arbitrary, but as it has been eliminated, there remain only the two independent variables $\alpha$ and $\beta$. For the minimum expense, the partial derivatives of P, relative to $\alpha$ and to $\beta$, must be nul separately, which will give the equations

$$(a+c)\cot.^2\alpha+(c-a')\cot.^2\beta+2(a+c)\cot.\alpha\cot.\beta-a-a'=0,$$

and $$(c-a)\cot.^2\alpha+(a'+c')\cot.^2\beta+2(a'+c')\cot.\alpha\cot.\beta-a-a'=0.$$

Subtracting one from the other, member by member, we obtain an equation of the second degree to determine the proportion of the cotangents or of the tangents. We deduce from it $\frac{\tan.\alpha}{\tan.\beta}=-1$, first value inadmissible, and $\frac{\tan.\alpha}{\tan.\beta}=$

$$\frac{2a+c-c}{2a'-c+c'}=\frac{2\xi'\left(1+\frac{m^2-1}{6m^2}q\right)+\xi_1-\xi}{2\xi''\left(1+\frac{m^2-1}{6m^2}q\right)-\xi_1+\xi}.$$

Elimination leads to

$$\tan.\alpha=\frac{Z}{2\xi''\left(1+\frac{m^2-1}{6m^2}q\right)+\xi-\xi_1}\text{ and }\tan.\beta=\frac{Z}{2\xi'\left(1+\frac{m^2-1}{6m^2}q\right)+\xi_1-\xi},$$

Z denoting the radical

$$\sqrt{4\xi'\xi''\left(1+\frac{m^2-1}{6m^2}q\right)^2+2(\xi_1-\xi)(\xi''-\xi')\left(1+\frac{m^2-1}{6m^2}q\right)-(\xi_1-\xi)^2+\frac{2(4m^2-1)}{3m}(\xi+\xi_1)(\xi'-\delta'')\left(1+\frac{m^2-1}{6m^2}q\right)}.$$

Consequently, the dependent variable $h$ will have, as a minimum, the value

$$h_1=\frac{lZ}{4m(\xi'+\xi'')\left(1+\frac{m^2-1}{6m^2}q\right)}.$$

In a girder consisting entirely of iron we have not to distinguish different materials, but the distinction of coefficients may exist from other causes. If, for example, we wish to impose upon the upper flange $\frac{1}{K}$ of the coefficient R imposed upon the lower one, we must substitute $KUt$ for $\xi$, $Ut$ for $\xi_1$, $Vt$ for $\xi'$, and $t$ for $\xi''$, P then denoting the total weight of the girder. But it must be remarked that the preceding calculations suppose that we may regard as constant the coefficients U and V, whilst it would be more exact to consider them as functions of the height. With this observation, when both flanges are affected with the same coefficient ($K=1$), we shall have

$$\frac{\tan.\alpha}{\tan.\beta}=V,\ h_1=\frac{l}{2m(V+1)}\sqrt{V+2m\frac{4m^2-1}{6m^2+(m^2-1)q}(V+1)U}.$$

61. Analogous calculations for the case in which $l=(2m+1)\delta$, Fig. 1539, would give as a minimum

$$\frac{\tan.\alpha}{\tan.\beta}=\frac{2\xi'\left(1+\frac{1}{6}q\right)+\xi_1-\xi}{2\xi''\left(1+\frac{1}{6}q\right)+\xi-\xi_1},\text{ and }h_1=\frac{lZ}{2(2m+1)(\xi'+\xi'')\left(1+\frac{1}{6}q\right)},$$

Z denoting the radical

$$\sqrt{4\left(1+\frac{1}{6}q\right)\left[\xi'\xi''\left(1+\frac{1}{6}q\right)+\xi\xi'+\xi_1\xi''+\frac{2}{3}(4m-1)(\xi+\xi_1)(\xi'+\xi'')\right]+(\xi-\xi_1)^2}.$$

For bridges constructed of plate iron, we should make $\xi=\xi_1=Ut$, $\xi'=Vt$ and $\xi''=t$; and, consequently, we should take, U and V being regarded as nearly constant,

$$\frac{\tan.\alpha}{\tan.\beta}=V,\text{ and }h_1=\frac{l}{(2m+1)(V+1)}\sqrt{V+\frac{(16m-1)U(V+1)}{3+\frac{1}{2}q}}.$$

But as a function varies little when near a minimum, we need not bind ourselves to follow strictly the rules obtained for the best proportion of the inclinations $\alpha$ and $\beta$. Thus they are generally made equal to each other, which is of a more satisfactory aspect.

62. *Deflection.*—The deflection of a simple lattice under the influence of a certain load will, in general, be easy to determine, when we have the sections of all the pieces and the exact figure of the system under a determinate load given. Then the load, the effect of which we wish to consider, will produce upon the several parts extensions or contractions easy to calculate, so that we can know the length of all the pieces after deflection, and the angles may afterwards be found by trigonometrical formulæ. The determining figure being known, we may deduce the curve of the flanges, the inclination at their extremities, and so on.

*Coefficient U applicable to the Flanges.—Coefficient of stiffness V.—Supplementary term Ω.—General form of the Formulæ for Weight.*—63. Coefficient U. This coefficient is intended to take into account the joint-plates of the flanges, and, beyond this, the impossibility, in practice, of reducing the latter exactly to the dimensions given by calculation.

1. *Joint-plates.*—The narrower an iron plate is, the longer it may be, so that small girders will cost proportionally less in joint-plates than large ones. But even for these latter, with plates of 0·80 mètre broad, for example, we may reckon upon lengths of 6 mètres. If at each joint we have a distinct joint-plate of 0·80 mètre long (0·40 mètre on each side of the joint), the quantity to be added the mètre of plate would be $\frac{0\cdot80}{6} = 0\cdot134$; but we may reduce this figure to 0·11, in consideration of the fact that the angle-irons of the flange may reach lengths of more than 12 mètres, and, consequently, will cost less in joint-plates than the plates of the flanges. This additional quantity of 0·11 may be regarded as the highest limit of the cost of joint-plates in the case of flanges of inconsiderable section composed of a single horizontal plate.

But when the maximum moment of rupture requires a strong section of flange, they are composed of several plates placed one upon another, and in that case a single joint-plate may serve for several joints placed after each other at intervals of 0·40 mètre. For example, a joint-plate of 1·60 mètre may cover three joints, which will reduce the additional quantity to 0·089. If we consider as an hypothetical limit an extremely low girder, such that the number of flange-plates shall be very great, the joint-plates would be as long as possible, and would have a tendency to weigh, for each joint covered, only the half of the weight of a distinct joint-plate of 0·80 mètre. We may thus include the joint-plates in our calculations by applying to the flanges a coefficient varying from 1·06 to 1·11, according as these latter are of great thickness (as if the height were nul), or, on the contrary, reduced to the minimum section that may practically be adopted without depriving the girder of its necessary rigidity, having regard to its other dimensions. These figures may be reduced a little in the case of plates 0·30 or 0·40 mètre broad, for example, which would allow us to reckon upon lengths greater than 6 mètres.

In heavy girders the number of plates diminishes towards the extremities, and it will be only in the middle that the coefficient may reach the limit 1·06 mètre. But, to compensate this, it often happens that at the extremities the first joints of the first plates may be covered by increasing slightly the length of the strengthening plates.

2. *Excesses of Section.*—The section of the flanges cannot be, throughout the length, reduced strictly to the value required by calculation, chiefly on account of the facts that the variation takes place by redans or gradations, and that at those points in which the moment of rupture is inconsiderable, we cannot practically reduce the section below a certain minimum. Instead of a small number of very thick plates, we shall find it a saving of material to employ a larger number of less thickness. But to abstract these thicknesses, let us consider, as above, the limiting cases. If, in the first place, the height were nul, the number of plates of ordinary thickness would be very great, and the redans would be only an imperceptible fraction of the total weight. If, on the contrary, the height reaches a value H, such that the weakest section that we wish to give to the flanges shall be sufficient in the middle, the flange will be prismatic instead of forming a parabolic volume, as the formulæ for the case of a continuous load suppose. To establish the prism in its integrity, we must multiply the value of the formula by a coefficient of 1·50, affecting generally the joint-plates which increase in the same proportion.

64. Thus the total coefficient U to be applied to the flanges for joint-plates and excesses of section may be taken equal to 1·06 for $h = 0$, and to $1\cdot11 \times 1\cdot50 = 1\cdot66$ for the limiting height H, which renders necessary a constant section in the flanges. We may, therefore, approximatively adopt, for any value of $h$, $U = 1\cdot06 + 0\cdot60 \frac{h}{H}$.

Usually the volume of the flanges is inversely proportional to $h$, so that the second term of U will give a quantity independent of $h$. Consequently, in seeking the most economical height, this constant term will have no influence, and we shall have simply to substitute 1·06 for U.

65. When the load is applied to certain intervals only, we may still admit the preceding expression of U. Yet, from the observation in 43, it will be more exact, if the bearing is divided into N intervals, to multiply the theoretical weight by $1\cdot50 \frac{N^2}{N^2-1}$, instead of 1·50, when there is occasion to return to the prismatic form in the case of the limiting height H. The coefficient will then be expressed by the function $U = 1\cdot06 + \left(\frac{1\cdot66\,N^2}{N^2-1} - 1\cdot06\right)\frac{h}{H}$

In simple lattice bridges, U has a tendency to increase slightly on account of the vertical rods serving to fix the bars, for these rods give a certain rigidity to the flanges which affects the resistance by easing the oblique bars, but at the same time by producing in the flanges deflecting strains and an unequal distribution of pressure. The best way to take this into account is to consider the two flanges as forming a solid whole resisting by its summit of resistance.

In girders loaded in a discontinuous manner, theory itself requires that the flanges should vary by sudden leaps from one section to another, but we cannot wholly get rid of the loss occasioned by the redans, on account of the difficulty of making the extra thicknesses prescribed by calculation coincide exactly with the usual thicknesses of plate iron.

66. The limiting height H to be considered in calculating U, may be taken equal to $\frac{(p+p')l^2}{8\,R\,s_0}$, $s_0$ being the minimum section that we wish to give, or that we may give, to the flanges. Consequently the value of U, considering only the case of a continuous load, will be $U = 1\cdot06 + 4\cdot80 \frac{R\,s_0\,h}{(p+p')l^2}$.

In a girder composed of triangles, we may regard as nearly constant the ratios $\frac{h}{l}$ and $\frac{s_0}{h}$; or at least if $s_0$ has a tendency to be proportionally a little stronger in small girders than in large ones, so that U will decrease slightly when $h$, and consequently $l$, increases; on the other hand, small girders cost less in joint-plates, and we may, therefore, regard U as expressed by $1{\cdot}06 + \frac{c}{p+p'}$, $c$ being a constant independent of $l$.

67. The preceding remarks concern straight girders. In bow-string girders, the joint-plates will have the same proportional value, but if the lower flange be straight, it will have a constant section, and there will be no loss for redans; besides, the section of the flanges is utilized quite to the extremities, whilst in straight girders there is always an excess of section at the ends. On the other hand, the bow and the chord, or stringer, in a bow-girder are fixed together at the ends by iron plates, which may be considered as forming an integral part of the flanges. When the height is inconsiderable, the strain between the bow and the chord will be great, and the gusset must be very long, but its mean breadth will be less than in a girder having a versed sine or rise of great magnitude. The coefficient U will vary but little in bow-string girders, and may be taken from 1·25 to 1·35.

68. *Coefficient of stiffness V.*—The pieces subject to compression have a tendency to deviate from the straight line when they have a weak section and great length; therefore, we are obliged in such cases to give them an excess of section, that is, instead of calculating them for a pressure of 6000000 kilos. the square mètre, we shall calculate them for a less pressure R; or having calculated them for 6000000 kilos., we must multiply the section so obtained by a coefficient $V = \frac{6000000}{R}$.

For flat bars, simply abutting against others at their extremities, we may, from the results of experience, admit the following figures:—

| Ratio of the length to the thickness $\frac{\lambda}{e}$ = | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Resistance the square millimètre .. .. = | 6·00 | 5·30 | 4·75 | 4·25 | 3·90 | 3·55 | 3·25 | 3·00 | 2·70 | 2·50 | 2·30 | 2·10 | 2·00 | 1·80 | 1·50 | 1·20 |
| Coefficient of increase V = | 1·000 | 1·132 | 1·263 | 1·412 | 1·538 | 1·690 | 1·846 | 2·000 | 2·222 | 2·400 | 2·609 | 2·857 | 3·000 | 3·333 | 4·000 | 5·000 |

The bars of lattice-girders being usually attached at their extremities by several rivets, may be regarded as welded or shut on, and we shall obtain additional security by observing the preceding data.

But flat bars have precisely the worst possible form to resist a strain of compression. This obliges us to increase the number and to place them near together, in order that each isolated part may have the necessary rigidity without giving to V too high a value. But the rivetings at the points where the bars cross each other are not all-sufficient, for the compressed bars are badly supported by being fixed to other bars as flexible as themselves; when the number of lattice-bars becomes great and, in consequence, the sections become very inconsiderable, the struts may yield by numerous deflections, twisting the braces, some in one direction, some in another, an effect similar to the wrinkles which show themselves upon a thin membrane stretched in a frame, when the angles of the frame are distorted. It follows, that we ought to employ flat bars only for girders of small height and heavily loaded, unless, indeed, the rigidity of the vertical middle part of the girder be sufficiently provided for by upright stays. If these stays serve no other purpose than to stiffen the part in question, it will generally be better to suppress them and to strengthen directly the resisting lattice-bars, either by increasing the section, or better, by adopting another form, such as that of angle or T iron. The braces, if nothing prevents it, should be constructed in the same way, because their rigidity, useless to themselves, lends a support to the struts. Sometimes these upright pieces are needed to fix tie-beams on one side only of the girder; it will be sufficient, in this case, if they project upon this same side, which will allow us to construct half of the oblique bars of stiff iron, the mouldings of which shall be turned in the opposite direction, to avoid cutting them away at the points where they cross each other.

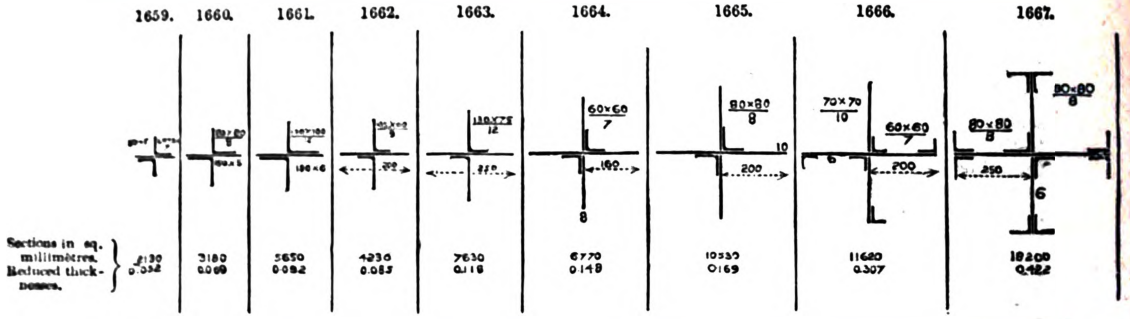
69. The influence of the form of the sections being established, it remains to be seen how we can consider the rigidity in the various cases which may present themselves.

Now the curve which a piece under the force of compression tends to assume is a real deflection, which requires, not a certain area of section, but a sufficient moment of resistance. In plate iron we may regard the thickness as being nothing but the ratio of the moment of resistance M expressed by the coefficient R = 6000000, to the section S expressed in square millimètres. Thus, to generalize the Table in the preceding section, it is sufficient in the ratio $\frac{\lambda}{e}$, applied to any section, to substitute the ratio $\frac{M}{S}$ for $e$, which we may call *reduced thickness*, or *imaginary thickness*, in the direction in which deflection is to be feared, and in which the moment of resistance M is taken.

70. When compressed bars are unsupported throughout their length, as is the case, for example, in girders formed of simple triangles, they should have a section possessing a rigidity equal in all directions. Such would be the round form, but it offers practical difficulties.

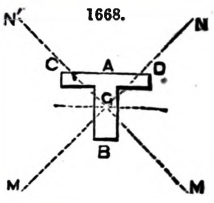
The section in the form of a cross with four equal branches, may be advantageously employed; it offers a moment of inertia constant in all directions. As to the moment of resistance, which depends on the distance of the fibre subject to the greatest strain from the centre of gravity, it is

$\sqrt{2}$ times greater in the direction of the lines bisecting the angles than in the direction of the arms; but as deflection will always take place in the weakest part, we can reckon only upon a reduced thickness, exceeding but little the dimension of one of the four arms, when these latter have a constant thickness. Figs. 1659 to 1667 represent some sections in the form of a cross,




composed of angle-iron and plate; this mode of construction causes irregularities of thickness, and the moment of resistance is affected by it according as the material is accumulated towards the centre or towards the extremities. Under each of the sections in the figures will be found the reduced thickness, taken in the direction of least stiffness when the branches are not identical.

71. The single T is more convenient for fixing than the section in the form of a cross, and it offers also a slight advantage from the point of view of resistance in the direction of the web. If we consider only the moment of inertia, it is easy to make it rigorously equal in all directions. To effect this, we have merely to proportion the arms and the web so that the moment of inertia in their respective directions C D and A B, Fig. 1668, shall remain the same. In fact, on account of the symmetry, the directions at 45° M N and M′ N′ give equal moments of inertia: the central ellipse of inertia will, therefore, offer two systems of equal rectangular diameters, which is found only in the circle. But, as is the case with the cross, the moment of resistance will be smaller in the principal directions than in the others; and if the reduced thickness is made equal in these two directions, we shall reckon only upon the value which it will so possess as if it remained constant in all directions.




The double T cannot be made to resist equally in its two chief directions, because this condition would require flanges of excessive breadth.

72. For bars of small dimension we may employ single angle-iron. This form offers least stiffness in the direction of the line bisecting the angle. If the angle-iron is thin and its branches have a breadth $c$, we may regard the minimum reduced thickness as equal to $\frac{c}{\sqrt{2}}$ or $0{\cdot}7\,c$. The central ellipse of inertia of such an angle-iron has its major axis double the minor; the minimum moment of inertia, a quarter of the maximum, is $\frac{2}{5}$ of the moment of inertia in the direction of one of the branches.

As an application of the foregoing, suppose a bar compressed by a strain of 5 tons, upon a free length of 3 mètres. An angle-iron of $0{\cdot}080$ mètre broad will give a minimum reduced thickness of about $0{\cdot}056$ mètre, and the ratio of the length to this thickness will be $\frac{3}{0{\cdot}056} = 53$. This value authorizes the adoption of $R = 2^{k}{\cdot}8$ per square millimètre, which leads to a section of 1790 square millimètres; this section will be obtained by giving to the angle-iron a mean thickness equal to $0{\cdot}012$ mètre. If this thickness did not suit, we should try an angle-iron of a different breadth.

We must proceed thus tentatively for every question of the same kind. We may calculate in advance the compressions which a certain number of model sections will bear, under various lengths, and these data will serve as a guide in determining, at sight, the modified sections which will suit given cases.

When the load is great and the length inconsiderable, we may adopt thicker sections and suppress the coefficient of stiffness. It is advisable, however, in such cases, to preserve an excess of rigidity.

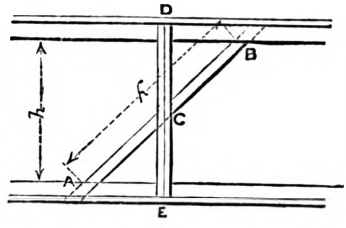
73. In multiple lattice-girders, a compressed bar is fixed, in the points where they cross, to other bars subject to tension, but which generally act more effectually against a deflection in the plane of the vertical because they cannot resist a deviation normal to this plane; in fact, if the braces are flexible bars, they will resist perfectly a strain of tension directed in the direction of their length, but very badly a transverse strain, which would bend them in a very marked manner. Thus, with regard to deflection in the plane of the vertical, we may consider the compressed bar as subdivided into shorter portions which may be stiffened separately; and as to deviation out of the plane of the vertical, it will be better not to reckon upon the tension of the braces, but only upon their rigidity which will supply what is wanting to the strut. The connection at the points where they cross each other may, therefore, improve the relation of the length to the reduced thickness, in the plane of the vertical because it reduces the length, and in the direction normal to

this plane because the rigidity of the braces assists that of the struts. However, this must not induce us, from the point of view of rigidity, to multiply the lattice as much as possible, for so we weaken each bar taken individually, and we should at length produce a girder the vertical portion of which would be liable to crumple up like a thin sheet of iron.

74. Let us consider the case of a *simple cross* formed by two bars of the same length and the same section: the strain of deviation which tends to throw the centre of the cross out of the plane of the vertical meets with an equal resistance from each of the two bars, omitting the special effect due to the tension of the brace; consequently the strut will be required to furnish only a moment of resistance or a reduced thickness, less by half than in the case in which it is isolated. Although its resisting section is not increased, it will be regarded as having the same reduced thickness as a single piece formed by the superposition of the two branches of the cross.

When the brace has less rigidity than the strut, the latter must be more rigid in the direction normal to the vertical. We may give it a reduced thickness equal to the sum of its own and that of the brace.

1669.




75. The vertical bars which are sometimes applied to a lattice to consolidate it, act in an analogous manner. Having no longitudinal strain to bear, the area of their section is of little consequence; they act only by their moment of resistance.

Suppose, for example, Fig. 1669, a flexible bar A B, held in its middle C by a rigid vertical bar D E. If the latter were absent, the bar A B could be subjected to a compression of 6 kilogrammes a square millimètre only under the condition that the ratio of its length $\lambda$ to its reduced thickness $\frac{M}{S}$ (see 69) did not exceed 15; which is equivalent to saying that it should have a moment of resistance at least equal to $\frac{\lambda S}{15}$ (the section S being expressed in square millimètres), precisely as if the point C were subjected to a transverse strain equal to $\frac{4S}{15}$; but as the bar is, of itself, incapable of resisting this strain, we may impose it upon the vertical bar which on this account should possess a moment of resistance equal to $\frac{\lambda' S}{15}$, the section S being, not its own, but that of the bar to be strengthened. Thus, by its less length, the vertical bar may furnish a determinate rigidity with a less moment of resistance: it is, however, generally better to increase the section itself of the bar and to suppress the vertical, for by that means we diminish the pressure per unity of surface, which requires less rigidity.

If the bar A B already possesses of itself a certain rigidity, it may take a portion $x$ of the strain of deflection in C. It will then be deflected by a quantity $\frac{x\lambda^3}{48EI}$ (E = modulus of elasticity, I = moment of inertia) which, on account of their being fixed together, must be equal to the versed sine of the arc assumed by the vertical bar; this condition gives the equation $x\left(\frac{\lambda^3}{I}+\frac{\lambda'^3}{I'}\right)=\frac{48\lambda'^3}{15I'}$, whence we deduce $x$. Consequently the vertical bar will be required to furnish only a supplementary moment of resistance equal to $\left(\frac{4S}{15}-x\right)\frac{\lambda'}{4}$.

We might apply analogous considerations to the less simple case in which C is not the middle either of the oblique or of the vertical bar.

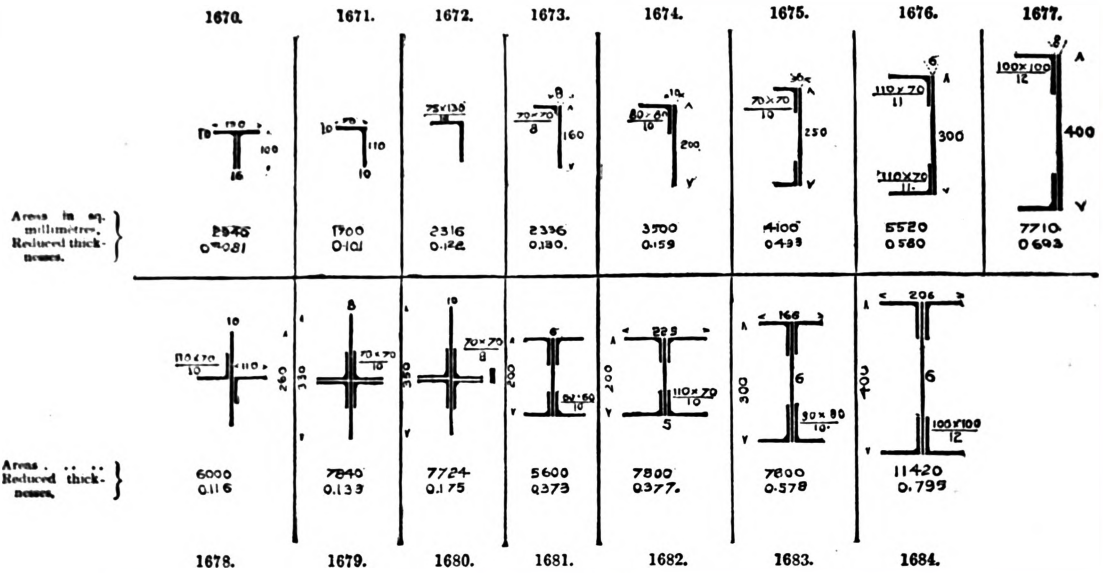
For a cross formed of two bars of the same section and the same free length $\lambda$, we shall have $x=\frac{2S}{15}$, and each bar will furnish, as we have already seen, a moment of resistance equal to the half of that which the compression-bar ought to have, if it were deprived of all assistance.

76. In a multiple lattice with flexible braces, the struts must be capable of greater transverse resistance in the direction normal to the vertical part of the girder than in the direction of the vertical part. Figs. 1670 to 1684 give as examples various sections, with their reduced thicknesses in the direction of greatest resistance; it will be seen that the forms in ⋃ or double T are very good, for they give reduced thicknesses which exceed by much the apparent dimension.

If, for instance, we have to construct a piece 8 mètres long, capable of resisting a maximum strain of compression of 10 tons only, the fifth section gives as the ratio of the length to the reduced thickness $\frac{8}{0\cdot159}=50$. According to the Table in 68, the piece ought to bear a strain of only 3 kilogrammes a square millimètre, and it is capable of bearing $3500\times3=10500$ kilogrammes, which is something more than sufficient. Adopting this section, the coefficient of stiffness would be 2·10; but it would be more advantageous to adopt a ⋃ iron of less weight.

77. The principle of increased section in the middle applied to the connecting-rods of machines, may also be adopted for the struts of very important girders. This may be effected by applying plates to the middle of the piece, precisely as in the case of girders loaded transversely.

It is always useful, in multiple lattices, to give to the tension-bars sections with projecting mouldings, at least as much as possible without making the area of the section exceed the value corresponding to a strain of 6 kilogrammes the square millimètre. When the length becomes so great that this condition of area, applied to the struts and braces, does not allow us to realize a sufficient




rigidity, we must have recourse to a coefficient of increase V, which may be exclusively applied to the struts, or divided between these and the braces when nothing prevents us from giving to the latter continuous projecting mouldings.

Sometimes accessory arrangements contribute to stiffen the vertical portion of girders; such is the case, for instance, Figs. 1580, 1585, where the cross-girders are placed in the middle of the height.

These various considerations no doubt are not exhaustive, but they will be sufficient to enable us to choose, in every case, the best forms; and when it may be done at a small cost, it will always be prudent to have an excess of rigidity.

78. When we wish to find as near as possible, without going through a complete calculation, the weight which a girder fulfilling certain given conditions would have, we may proceed as follows to find the value of the mean coefficient V to be applied to the parts of the lattice under compression.

We calculate the strains $Q_1$ and $Q_2$ upon the strut which bears the least strain (in the middle), and upon the one which bears the greatest strain (at the end); then, having regard to their length, we consider what sections it would be necessary to give them, and we deduce the coefficients of stiffness $v_1$ and $v_2$, special for these two bars. The total weight of the struts will then be nearly proportional to the mean $\frac{1}{2}(Q_1 v_1 + Q_2 v_2)$ whilst if the question of rigidity did not interfere, it would be proportional to the mean $\frac{1}{2}(Q_1 + Q_2)$ of the limiting strains; we may thence conclude approximatively $V = \frac{Q_1 v_1 + Q_2 v_2}{Q_1 + Q_2}$.

79. If some of the end struts could support a strain of 6 kilogrammes, the general coefficient would be smaller still. We should then seek the least section under which a strut can bear 6 kilogrammes, having regard to its free length and other circumstances, and determine the load $Q_3$ which it would carry with this section; then we should make approximatively

$$V = \frac{Q_2^2 - Q_1 Q_2 + Q_1 v_1 (Q_3 - Q_1)}{Q_2^2 - Q_1^2}.$$

80. The mean coefficient V may also be expressed by means of the variable coefficient $v$ applicable to the successive bars, by making $V = \frac{\Sigma F v}{\Sigma F}$. We might obtain from section 6 the values of F and $\Sigma F$; but to calculate $\Sigma F v$, we should have to express the law of variation of $v$ according to that of the strains. Now this law would be too complicated or too arbitrary to lead by this method to a satisfactory result, and it is preferable to trust to the approximative formula in section 78.

81. By increasing the height of a girder we weaken its middle, or vertical portion, and this obliges us to raise the value of the coefficient V in order to preserve a sufficient rigidity.

To find the *mode of variation of V with the height h* of the girder, we may remark in the first place that, according to the values of the Table in 68, as long as the ratio $\frac{\lambda}{e}$ does not exceed 50 or 55, V will be accurately enough represented by the function $0{\cdot}57 + \frac{1}{35}\frac{\lambda}{e}$, with the condition, however, that it cannot become less than unity. In this expression, the reduced thickness $e$ depends on the form and area of the section, and this area is a function of the load Q which the piece supports and of the coefficient V: it is expressed by $\frac{Q V}{R}$.

If the section vary in such a way that on dividing it by the reduced thickness, the quotient $b$ is constant, we shall have $e = \frac{QV}{Rb}$, and consequently $V = 0{\cdot}57 + \frac{1}{35}\frac{R\lambda b}{QV}$, whence

$$V = 0{\cdot}29 + \sqrt{0{\cdot}082 + \frac{R\lambda b}{35Q}}$$

For example, for girders composed of triangles or crosses, expressing the length $\lambda$ of the bars and their strain Q by means of the height $h$ of the girder and the whole strain F, we shall have $V = 0{\cdot}29 + \sqrt{0{\cdot}082 + \frac{Rb}{35F}h}$. For a multiple lattice of the $i$ degree, we have only to change F into $\frac{F}{i}$.

If the section varied while remaining similar to itself, the quotient of the square of the section by the reduced thickness would be constant, and V would be determined by an equation of the third degree.

Thus, keeping to the simplest case first considered, V will be expressed in terms of the height by formulæ of the form $a + \sqrt{b + ch}$. But as there is nothing absolute in the value of this coefficient, nor in the relation of the section to the reduced thickness, on account of the great diversity of form, we may content ourselves, in the investigation of the most economical heights, with replacing V by a rational function of the first degree $a + bh$, determined by means of two particular values of this coefficient for heights differing not too widely, but including between them the height sought. This is equivalent to replacing an arc by its chord.

82. Circumstances other than the condition of rigidity may oblige us to increase the weight of the vertical portion of a girder beyond the limits prescribed by theory. For example, in a multiple lattice in which the bars are very numerous, their section is not made to vary in a perfectly continuous manner, but only by successive groups; so that the greater portion of them will possess a slight excess of weight. Then again in the parts in which the stress is inconsiderable, it often happens that we cannot in practice make the bars so slender as they are required to be by calculation. Besides, when the section is inconsiderable, a single rivet-hole weakens it in a proportionally great degree. This is another reason for increasing the dimensions. These several augmentations might give occasion for a new coefficient applied to the whole of the vertical portion of the girder, but it will simplify the matter to include them in the coefficient V by raising its value sufficiently high.

83. *Supplementary term* $\Omega$.—To complete the computation of the weight of a girder, we must include certain accessory pieces the dimensions of which are nearly independent of the height of the girder, and which may be represented by a constant additional term $\Omega$. Such are, for example, in lattice-girders, the gussets at the points where the bars cross each other, joint-plates and other contrivances for making the rivets offer a double section to the strain upon them. On the other hand, these special pieces are partly compensated by the fact of the lattice-bars ending at the edge of the longitudinal angle-irons of the flanges, so that their length is slightly inferior to that supposed in the formulæ. Sometimes certain accessory pieces may be considered as increasing in a certain proportion with the height; in these cases we may include them in the coefficients U or V according as they belong to the flanges or to the vertical portion.

84. *General form of the Formulæ giving the Weight of Girders, and the most advantageous Heights.*—The total weight of a girder is obtained by adding the terms referring respectively to the flanges, to the vertical portion and to the accessories independent of the height. Dividing by the length of bearing, we shall have the mean weight of the lineal mètre.

In this mean weight, the flanges will appear as a quantity expressed by $\frac{2GtU}{h}$, G denoting the mean ordinate of the locus of the maximum moments of rupture (that is, $\frac{1}{12}(p+p')l^2$ in the case of a single bay and a continuous load). As U is of the form $a + bh$ (64), the flanges are divided into a part inversely proportional to $h$, and a part which is constant.

In girders composed of simple triangles or crosses, $\delta$ being constant, the inclination of the bars is a function of the height, and the pieces of the vertical portion generally make, a mètre of length, a weight of the form $\frac{G't(1+V)}{l\delta}\left(h + \frac{\delta^2}{4h}\right)$, G' denoting the mean ordinate of the locus of the maximum stress, the value of which ordinate is $\frac{1}{4}(p+p')l\left(1+\frac{1}{6}q\right)$ in the case of a continuous load. Admitting that $1 + V$ is expressed by $a + bh$ (81), the weight in question will give rise to terms in $h^2$, in $h$, in $\frac{1}{h}$, and to a constant term.

In multiple lattice-girders in which the inclination of the bars is 45°, or else keeps a certain other constant value, as in the case of solid girders, the theoretical vertical position would have a constant weight. But, in such cases, the rigidity is usually obtained by the addition of special stays, vertical or inclined, the section and length of which increase with $h$, so that their weight will be expressed under the form $(\kappa + \kappa' h)h$.

85. Thus, the weight of the lineal mètre of girder will be generally given by formulæ of the following form: $\frac{P}{l} = \frac{A}{h} + B + Ch + Dh^2$. The corresponding height at the minimum expense

will be given by the equation of the third degree: $A = (C + 2D\,h)\,h^2$, whence we deduce the real value:

$$h = \sqrt[3]{\frac{1}{4D}}\left\{\sqrt[3]{A - \frac{C^3}{54D^2} + \sqrt{A^2 - \frac{AC^3}{27D^2}}} + \sqrt[3]{A - \frac{C^3}{54D^2} - \sqrt{A^2 - \frac{AC^3}{27D^2}}}\right\} - \frac{C}{6D}.$$

But as it is always enough to know this height within 1 décimètre, it will be a saving of time to solve the equation tentatively. As a function varies but little when near a minimum, we may without much increasing the expense adopt heights less than those given by calculation, and we find an additional reason for doing this in the fact that the ties or cross-pieces generally increase with the height. We might, it is true, seek directly the conditions of the minimum of weight for the whole flooring, instead of a single girder.

86. Sometimes, for the sake of simplicity, we may regard V as a fixed coefficient which may conveniently be forced a little; in this case, V being constant, we shall arrive for simple lattices at formulæ of the form $\frac{P}{l} = \frac{A}{h} + B + C\,h$, and taking $h = \sqrt{\frac{A}{C}}$, we shall have as the minimum value, $\frac{P}{l} = 2\sqrt{AC} + B$. It is evident that an alteration of height, even if considerable, has but a small influence; for if, by way of example, instead of $\sqrt{\frac{A}{C}}$, we take $h = \kappa\sqrt{\frac{A}{C}}$, the term $2\sqrt{AC}$ will be merely changed into $2\sqrt{\frac{A}{C}}\,\frac{1+\kappa^2}{2\kappa}$.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Now $\kappa = 0{\cdot}9$ | gives | $\frac{1+\kappa^2}{2\kappa} = 1{\cdot}0056$ | | And $\kappa = 1{\cdot}1$ | gives | $\frac{1+\kappa^2}{2\kappa} = 1{\cdot}0045$ | |
| „ $0{\cdot}8$ | „ | „ | $1{\cdot}0250$ | „ $1{\cdot}2$ | „ | „ | $1{\cdot}0167$ |
| „ $0{\cdot}7$ | „ | „ | $1{\cdot}0643$ | „ $1{\cdot}3$ | „ | „ | $1{\cdot}0346$ |
| „ $0{\cdot}6$ | „ | „ | $1{\cdot}1333$ | „ $1{\cdot}4$ | „ | „ | $1{\cdot}0571$ |
| „ $0{\cdot}5$ | „ | „ | $1{\cdot}2500$ | „ $1{\cdot}5$ | „ | „ | $1{\cdot}0833$ |
| „ $0{\cdot}4$ | „ | „ | $1{\cdot}4500$ | „ $2{\cdot}0$ | „ | „ | $1{\cdot}2500$ |

An increase of height above $\sqrt{\frac{A}{C}}$ produces a less loss than an equal diminution, but in almost every case it will be a diminution that we shall have to make.

It will be well to make a verification afterwards to ascertain whether the height $\sqrt{\frac{A}{C}}$, or at least the reduced height adopted, does not require a value of V superior to that which we have introduced into the calculation.

This method gives too great height, and, therefore, the reduction which it will be necessary to make will be more considerable than when we employ the more exact method of the preceding section.

87. *Girders of Simple Triangles.—Formulæ of the Weight a lineal mètre, in the case of Bars of Equal Inclination.*—To find the total weight P of girders of simple triangles, formed by bars of equal inclination, we have only to add together the weights of the flanges, the struts, and the braces, given by the formulæ $p$, for the particular cases in which $\alpha = \beta$. As the total length of the girder exceeds its bearing, we shall give only the weight per lineal mètre, found by dividing P by the bearing $l$, and it is understood that when the total weight, including the ends, is required, the weight of the lineal mètre is to be multiplied, not by the bearing, but by the total length, say by $1{\cdot}045\,l$ or $1{\cdot}097\,d$, $d$ being the free span, according to what was said in 37.

1. *Load on the lower side.*—If $l = 2m\delta = N\delta$, we shall have, $\Omega$ being an additional term for the accessories independent of $h$,

$$\frac{P}{l} = \frac{1}{2}\,m(p+p')\,t\left(1 + \frac{m^2-1}{6m^2}\,q\right)\left\{\frac{\delta^2}{h}\left[\frac{(4m^2-1)\,U}{3m + \frac{m^2-1}{2m}\,q} + \frac{1+V}{4}\right] + h(1+V)\right\} + \Omega,$$

or

$$\frac{P}{l} = \frac{1}{4}\,(p+p')\,t\,l\left(1 + \frac{N^2-4}{6N^2}\,q\right)\left\{\frac{l}{Nh}\left[\frac{2}{3}\cdot\frac{N^2-1}{N}\cdot\frac{U}{1 + \frac{N^2-4}{6N^2}\,q} + \frac{1+V}{4}\right] + \frac{Nh}{l}(1+V)\right\} + \Omega,$$

a formula applicable when N is even.

When $l = (2m+1)\delta = N\delta$, we have

$$\frac{P}{l} = \frac{m(m+1)}{2m+1}\,(p+p')\,t\left(1 + \frac{1}{6}\,q\right)\left\{\frac{\delta^2}{h}\left[\frac{2}{3}(2m+1)\cdot\frac{U}{1 + \frac{1}{6}\,q} + \frac{1+V}{4}\right] + h(1+V)\right\} + \Omega;$$

or

$$\frac{P}{l} = \frac{1}{4}\cdot\frac{N^2-1}{N}\,(p+p')\,t\,l\left(1 + \frac{1}{6}\,q\right)\left\{\frac{l}{Nh}\left(\frac{2U}{3 + \frac{1}{2}\,q} + \frac{1+V}{4N}\right) + \frac{h}{l}(1+V)\right\} + \Omega,$$

a formula applicable when N is odd.

The flanges do not change whether N be even or odd; but the lattice decreases slightly when N is odd, in the proportion of $N^2 - 1$ to $N^2$.

2. *Load on the upper side.*—For $l = 2m\delta = N\delta$, we shall have

$$\frac{P}{l} = \frac{1}{48m}(p+p')t\left[6(4m^2-1) + \left(4m^2 - 1 + \frac{3}{2m}\right)q\right]$$
$$\left\{\frac{\delta^2}{h}\left[\frac{(32m^2 - 8m + 3)U}{6(4m^2-1) + \left(4m^2 - 1 + \frac{3}{2m}\right)q} + \frac{1+V}{4}\right] + h(1+V)\right\} + \Omega,$$

which amounts nearly to

$$\frac{P}{l} = \frac{N^2-1}{4N}(p+p')tl\left(1 + \frac{1}{6}q\right)\left\{\frac{l}{Nh}\left[\frac{2U}{3 + \frac{1}{2}q} + \frac{1+V}{4N}\right] + \frac{h}{l}(1+V)\right\} + \Omega,$$

a formula identical with the last of the case in which the load is on the lower side, except that here N is even.

And if $l = (2m+1)\delta = N\delta$, we have

$$\frac{P}{l} = \frac{1}{12}(p+p')t\left[3(2m+1)^2 + m \cdot \frac{4m^2 + 6m - 1}{2m+1}q\right]$$
$$\left\{\frac{\delta^2}{2h}\left[\frac{32m^3 + 48m^2 + 16m + 3}{3(2m+1)^3 + m(4m^2 + 6m - 1)q}U + \frac{1+V}{2}\right] + \frac{h(1+V)}{2m+1}\right\} + \Omega;$$

or

$$\frac{P}{l} = \frac{1}{4}(p+p')tl\left(1 + \frac{1}{6}q\right)\left\{\frac{l}{Nh}\left[\frac{2}{3} \cdot \frac{N^2-1}{N} \cdot \frac{U}{1 + \frac{1}{6}q} + \frac{1+V}{4}\right] + \frac{Nh}{l}(1+V)\right\} + \Omega,$$

a formula in which N is odd, and which is obviously the same as the first of case 1.

88. *Examples.—Girder of* 28 *mètres bearing*, supporting, on the upper side, a load of 3500 kilogrammes to a mètre, Figs. 1685 to 1689; $p = 1100^k$ (the girder itself weighing 400), $p' = 2400^k$, $q = 0{\cdot}686$, $m = 4$, and, consequently, $\delta = 3^m{\cdot}50$, $h = 3^m{\cdot}30$.

As the girder is lightly loaded, we must seek to diminish as much as possible the least section of the flanges, without, however, reducing too much their breadth, which we will fix at $0^m{\cdot}400$. To diminish the breadth of the vertical ribs, projecting gussets are placed at intervals, to which the struts and braces may conveniently be attached. Those struts which are most heavily loaded have a section in the form of a cross, favourable to rigidity in all directions; one of the angle-irons passes behind the gusset to avoid the necessity of cutting it away at the extremities; and, consequently, some of the rivets offer a double section. Instead of filling the whole of the space above the gusset to make this angle-iron solid with the rest of the bar, it is sufficient to fill it in part only The middle bars require fewer rivets, but it has been necessary to increase their theoretical section to obtain the required rigidity.

The lower vertical rib is only $0^m{\cdot}300$ broad· but the upper could not be reduced below $0^m$ 350, because the flange should be rigid to resist compression, because in the present case it might be required to serve as a minor longitudinal girder, and because we might have occasion to affix to it a light corbel, in which case this breadth of $0^m{\cdot}35$ is barely sufficient. The brackets may be placed in the middle of the intervals to be out of the way of the bars. It is solely for the purpose of forming a minor longitudinal girder that the upper flange has been produced, and the vertical supports added at the ends.

We find by calculation the total weight of the girder to be 11200 kilogrammes, say 380 kilogrammes the lineal mètre.

The flanges weigh together 8070 kilogrammes, including the gussets for fixing the bars; but to determine the value of U, it is better to consider only the weight of 7400 kilogrammes, which we obtain by deducting the projection of the gussets, and reckoning with the vertical rib only the joint-plates which would be needed if it were not interrupted at short intervals by the gussets. Dividing by the whole length $29^m{\cdot}40$, we find that the flanges make together 252 kilogrammes the lineal mètre. The formula would give $177{\cdot}3\,U$; we shall, therefore, have $U = \frac{252}{177{\cdot}3} = 1{\cdot}42$, a value which includes the extensions at the ends.

However great the height of the girder might be, we could hardly compose the flanges of less than two angle-irons of 100/100/12 millimètres, a vertical rib of 300/10, and a horizontal plate of 350/8: this would form a sufficient section in the middle if the height were $5^m{\cdot}50$, and it would remain constant throughout the bearing. By the formula of 64, we should find again $U = 1{\cdot}06 + 0{\cdot}60\,\frac{3{\cdot}30}{5{\cdot}50} = 1{\cdot}42$.

The extra weight of 670 kilogrammes occasioned by the presence of the gussets, is reduced to 500 kilogrammes when diminished by the saving effected by the fact of the real length of the bars being a little less than their theoretical length, since they terminate at the edge of the angle-irons of the flanges. Hence we conclude that $\Omega$ is here equal to $\frac{500}{29{\cdot}40} = 17$ kilogrammes the lineal mètre of girder, say the 0·047 of the total weight of the principal pieces. This is a great deal, but we may reduce this value by giving the gussets a thickness of 8 millimètres only.

The oblique bars weigh 2600 kilogrammes, but the saving effected in their length has just been attributed to the term $\Omega$, we must, therefore, suppose them to possess the weight 2770

kilogrammes, which they would have with their theoretical length. Comparing with the formula, V = 1·34.

If we wished to compute V approximatively, without going through a complete calculation, we should have considered only one extreme and one middle bar. The latter, for a maximum strain of $Q_1 = 9\frac{1}{2}$ tons, gives $V_1 = 2\ 26$ with the section adopted; and the other, for a strain $Q_2 = 52{\cdot}6$ tons, gives $V_2 = 1{\cdot}07$, including the filling. The formula of 78 then gives $V = \frac{Q_2 V_2 + Q_1 V_1}{Q_2 + Q_1} = 1{\cdot}29$, a value which we must increase a little, because in the formulæ one of the bars of the middle triangle has been regarded as a brace, and, on this account, exempted from the coefficient V, whilst in reality both bars of this triangle should be able to serve, each in its turn, either as strut or as brace.

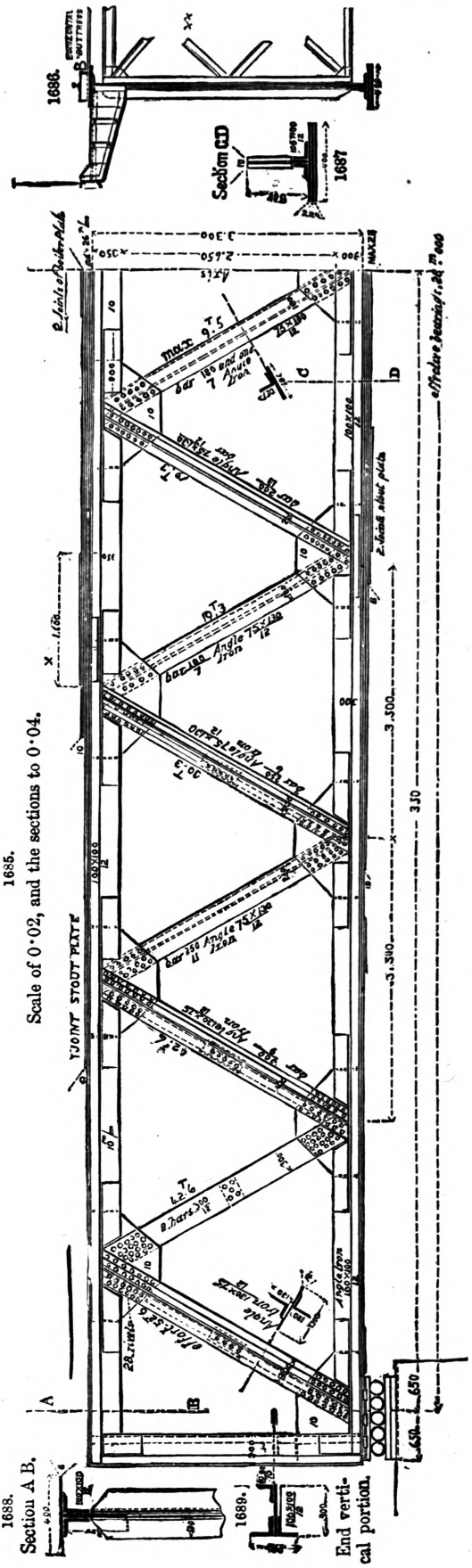
To discuss the height of the girder, we must first seek an approximative expression of V in terms of the height. To this end, let us consider, by way of example, a height of 5 mètres; we shall then have $Q_2 = 48{\cdot}6$ tons and $Q_1 = 8{\cdot}7$ tons, and the free length of the bars between the gussets will be about 4 mètres. For the one which is the most heavily loaded, a section in the form of a cross with four arms of 150/10, held together by four angle-irons of 70/70/10, will give $V_2$ = about 1·40; and for the weakest bar, a cross composed only of a bar of 140/6 and of two angle-irons of 70/70/10, will give $V_1 = 2{\cdot}40$. We thence conclude V = 1·55, say 1·60 on account of the observation made above. Knowing the values of V for two different heights, it is evident that we may adopt nearly $1 + V = 1{\cdot}70 + 0{\cdot}19\,h$.

Substituting this expression in the formula of the preceding section (case 2 for N even), we find that the minimum expense is given by a height of about $4^m{\cdot}40$. In fact, with this height, we should have 1 + V = 2·54, U 1·54, and, consequently, the weight of the lineal mètre descends to 350 kilogrammes, Ω included; whereas with $h = 3^m{\cdot}30$, 1 + V = 2·33, U = 1·42, the formula gives 370 kilogrammes. These weights should be increased a little to take sufficiently into account the end upright pieces, which really form no portion of the girder, but serve only to support the rail upon the abutment. It is obvious that if the height allowed permits, it may be of some use to increase slightly the height of the plan, to carry it to $3^m{\cdot}60$, for instance, but it would be useless to go beyond that, for the cross-pieces would increase without giving any sensible advantage to the girder. We might, in a more general manner, have sought the most advantageous height, by considering the whole of the flooring, and expressing the cross-pieces themselves as a function increasing with *h*.

89. *Girder of* 56 *mètres bearing, with a load on the lower side of* 7000 *kilogrammes the mètre*, Figs. 1690 to 1700; $p = 3000^k$ (the girder itself weighing $1300^k$), $p' = 4000^k$, $q = 0{\cdot}572$, $m = 4$ or N = 8, $\delta = 7^m$, $h = 7^m$.

The load supposes both lines loaded simultaneously; otherwise, for one line only, $p'$ would not exceed 3000 kilogrammes, and we might reduce by about $\frac{1}{7}$ the weight of the girder, allowing it a strain of 7 instead of 6 kilogrammes in the exceptional case of two heavily-laden trains crossing the bridge at the same time.

Cross-bracing behind the compression-bars.



The interval $\delta$ can be raised to 7 mètres only on the supposition that there are two cross-girders for each section or division of flange, which subjects the bottom flange to a deflecting strain; but this strain may be neglected, having regard to the form of the section and to the other arrangements adopted.

The following Table gives the strains upon the pieces:—

| | Upper Flange. | | | | Lower Flange. | | | | Struts or Braces. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Numbers of the divisions, or of the bars.. .. .. | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Maximum strain, in tons.. | 392 | 369 | 294 | 172 | 386 | 337 | 239 | 92 | 51 | 94 | 141 | 192 |

The flanges are hollow and have a double vertical rib, which allows the bars to be very firmly fixed. The two triangles next the abutment are besides provided at their extremities with joint-plates forming a kind of fork, which enables the rivets, or at least many of them, to offer a double section. By this means we may place upon each rib thirty rivets, twenty-four of which offer a double section. This gives for the foot of the end brace, for example, a total of 108 shearing sections, capable of resisting a strain of 216 tons if the rivets have $0^m \cdot 025$. The thickness of the double vertical ribs is $0^m \cdot 012$. In the last triangle it is well to strengthen them to increase their resistance to a shearing force; this is accomplished by adding broad gussets of $0^m \cdot 012$. At the foot of the end brace there is no projecting gusset; but the thickness of the rib is doubled by the projecting of a joint-plate.

For the intermediate triangles, it is useless to have recourse to double shearing sections.

The struts have a hollow form, very favourable to resistance to compression, as the moment of resistance is rendered as great as possible in the two directions. The transverse plate of 400/8 is not reckoned in the resisting section; it has been added to connect the other pieces of the bar so as to render them solid, and this plate or flat bar constitutes the principal element of the coefficient V. Its effect is completed by three triangles or rods placed on the other side, at equal intervals.

The braces are composed of two pieces left unconnected, except in the middle bar, which is as much a strut as a brace, and which, for this reason, has been stiffened by a continuous strip of plate iron connecting the two pieces. It would have been somewhat more economical to have substituted a light lattice for this continuous plate; but it has the advantage of giving more body to the pieces and of diminishing the pressure on each unit of surface.

The girder weighs 75 tons, say 1293 kilogrammes a lineal mètre of length (58 mètres).

The flanges with their joint-plates weigh 50 tons, say 862 kilogrammes the mètre, which gives $U = 1 \cdot 29$.

The plates or gussets added to the end bars to obtain a double section of rivet, are in part covered by the saving resulting from the fact of the lengths of the bars being a little less than their theoretical lengths.

The excess, 2050 kilogrammes, increased by the angle-iron forming a hand-rail, becomes 2400 kilogrammes; say $\Omega = 42$ kilogrammes a lineal mètre, or the $0 \cdot 032$ of the whole weight.

The bars themselves make up a weight of 22600 kilogrammes, not including the accessories reckoned in $\Omega$. Hence we deduce $V = 1 \cdot 25$.

Here the form favourable to rigidity given to the struts, would allow of the height being increased without much augmenting V.

It would be reckoning liberally to take, for example, $1 + V = 1 \cdot 55 + 0 \cdot 10\, h$ when near a height of 7 mètres. The best height is then theoretically given by the equation $h^2 (h + 7 \cdot 75) = 1346$, and is about 9 mètres. Indeed, with this value we should have $V = 1 \cdot 43$, $U\ 1 \cdot 36$, and, consequently, the weight $= 1 \cdot 250$ kilogramme per mètre, $\Omega$ included; whereas with $h = 7$, $V = 1 \cdot 25$, $U = 1 \cdot 29$, and $\Omega = 42$, the formula gives 1295 kilogrammes, which agrees with the direct calculation.

These two weights, however, differ but little, which justifies the adoption of the height 7 mètres, as being the more convenient.

90. The object of formulæ of weight is to enable us to compute the cost of a girder subject to given conditions, without making a plan and a calculation of it. But, if we wish to attain a certain exactness, it will be well to consider approximatively arrangements which may be adopted, and which affect U and V.

By way of example, let us suppose it is required to find the weight of a girder of the same form as that of 56 mètres which we have been considering, but the load of which is reduced by one-half (3500 kilogrammes instead of 7000). It will be advisable to retain the hollow form of the struts and the double-ribbed flanges; but these ribs may be, for example, $0^m \cdot 400$ broad by $0^m \cdot 012$ thick, for only half the former number of rivets will be required. If the least section of flange comprises besides a horizontal plate of 550/8 and four angle-irons of 100/100/12, it will become sufficient in the middle when the height of the girder rises to 12 mètres; so that we may consider

$$U = 1 \cdot 06 + 0 \cdot 60 \frac{7}{12} = 1 \cdot 41.$$

The strongest strut supporting 96 tons $= Q_2$, will have sufficient rigidity if we give it the hollow form composed of two side plates of 350/11, a back plate of 350/8, and four angle-irons of 100/100/12; this would give to the bar a coefficient $v_2 = 1 \cdot 22$. The weakest strut, for the strain $Q_1 = 25\frac{1}{2}$ tons, may be formed of two side plates of 220/6 and back plate of 350/6, and four angle-irons of 60/60/8; this will make $v_1 = 1 \cdot 96$. Consequently we shall compute the general coefficient of stiffness at $V = \dfrac{Q_2 v_2 + Q_1 v_1}{Q_2 + Q_1} = 1 \cdot 38$.

With the values thus found for U and V, the formula will give 680 kilogrammes as the weight

of the lineal mètre of girder, a value which must be increased a little to include Ω, remarking, however, that this additional term will be considerably less than in the case of the double load.

The values of U and V are rather high, but they may be reduced a little by adopting a less height than 7 mètres, which will be warranted by a load reduced to 3500 kilogrammes.

91. *Tables of Weights.*—The best height is an implicit function of the load, in virtue of V which diminishes when the load increases.

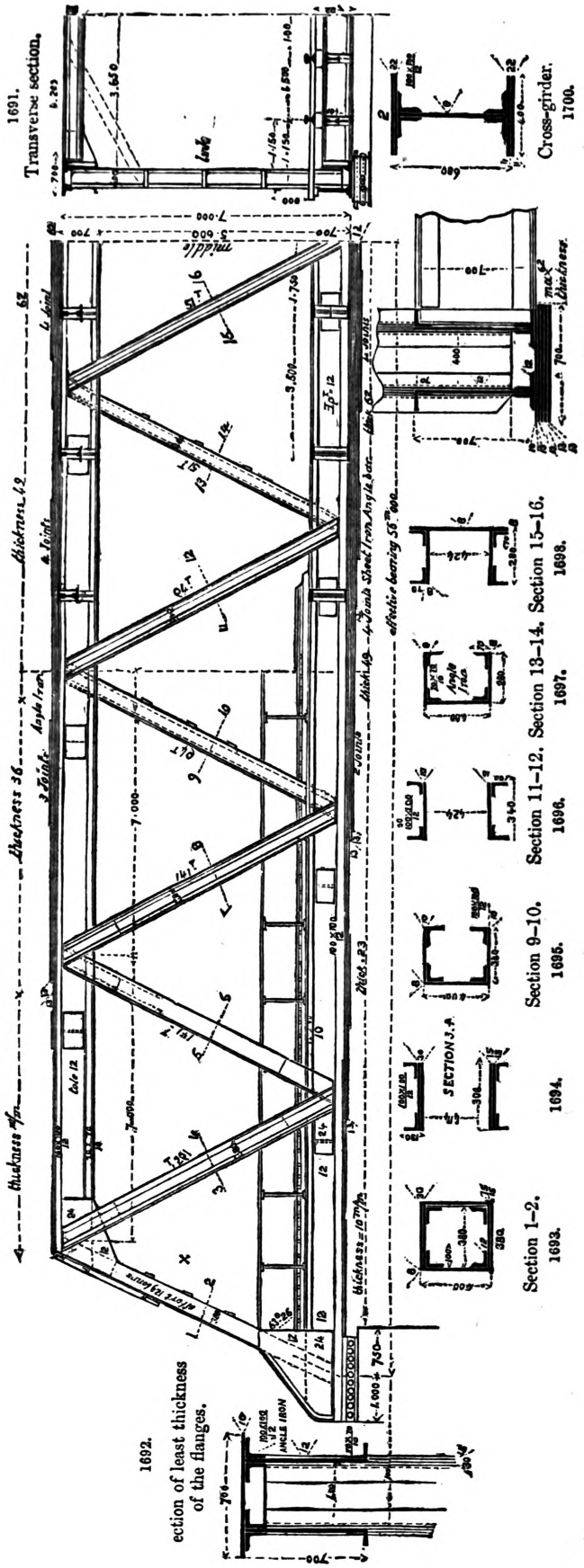
We must, therefore, distinguish the case of girders lightly loaded, supporting only one rail, for example, and that of girders heavily loaded, or supporting the whole line. In the former case, we will suppose $h = 0{\cdot}11\,l$, and in the latter $h = \frac{1}{8}\,l$.

If in the formula of 66, we suppose $\frac{R\,s_0}{h} = 20000$, we shall have for a girder carrying 3500 kilogrammes, and having a height 0·11 of the bearing, $U = 1{\cdot}06 + \frac{4{\cdot}8 \times 20000 \times \overline{0{\cdot}11}^2}{3500} = 1{\cdot}39$, say 1·40; and for a girder carrying 7000 kilogrammes, and having a height equal to $\frac{1}{8}\,l$; U = 1·28, say 1·30. V will be taken equal to 1·35 for light girders, and 1·25 for girders heavily loaded.

With these data we form the Tables IX. A and IX. B, giving the values of $\frac{P}{(p+p')\,l^2}$, Ω not included: that is, the weight of the lineal mètre of girder, for the given values of N and $q$, will be obtained by multiplying the corresponding number of the Table, by the quantity $(p + p')\,l$, and adding a certain sum for Ω, as will be shown hereafter.

If the girder were loaded on the upper side, the weight would be slightly diminished when N is even, and increased when N is odd.

There is evidently an advantage in taking N small; because in that case the flanges decrease in weight with the bars which approach the direction of 45°.



92. In large bridges, we may usually give sufficient dimensions to the vertical ribs of the flanges to enable us to reduce to a comparatively trifling matter, or to avoid altogether, the addition of special gussets. Thus the additional term $\Omega$, occasioned by the accessories, for 1 mètre of girder, will increase less rapidly than the bearing, whilst the weight of the mètre of girder increases as the bearing. It follows from this that the ratio of $\Omega$ to the total weight diminishes when the bearing increases. For light girders, we must add to the numbers of the first Table a sum varying, for example, from 5 to 2 per cent., according as the bearing varies from 20 to 80 mètres, and for the heavy girders of the second Table, from 6 to 3 per cent.

In the case of spans of 20, 60, and 80 mètres, we may allow the following loads for girders carrying either one or two rails:—

| | $l = 20$ m. Girders carrying | | $l = 60$ m. Girders carrying | | $l = 80$ m. Girders carrying | |
|---|---|---|---|---|---|---|
| | One Rail. | Two Rails. | One Rail. | Two Rails. | One Rail. | Two Rails. |
| | kilos. | kilos. | kilos. | kilos. | kilos. | kilos. |
| $p$ Exterior dead weight .. .. | 700 | 1400 | 700 | 1400 | 700 | 1400 |
| $p$ Weight of the girder itself .. | 300 | 500 | 900 | 1400 | 1200 | 2100 |
| Moving load $p'$ .. .. .. .. | 2500 | 5000 | 2000 | 4000 | 2000 | 4000 |
| Total load a mètre, $p + p'$ .. | 3500 | 6900 | 3600 | 6800 | 3900 | 7500 |

Let us suppose besides N = 7 for bridges of 20 mètres, 8 for those of 30 to 60 mètres, 9 for 70 mètres, and 10 for 80 mètres; and let us add the sums for $\Omega$ indicated above. We shall have the following approximative weights:—

| Spans .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres. 80 |
|---|---|---|---|---|---|---|---|
| Weight a mètre of a girder carrying one rail $\left(\frac{h}{l} = 0{\cdot}11\right)$ .. .. .. .. .. .. .. | Kilos. 265 | Kilos. 405 | Kilos. 545 | Kilos. 680 | Kilos. 820 | Kilos. 1000 | Kilos. 1220 |
| Weight a mètre of a girder carrying two rails $\left(\frac{h}{l} = \frac{1}{8}\right)$ .. .. .. .. .. .. .. | 460 | 685 | 910 | 1140 | 1365 | 1690 | 2090 |

These weights offer a saving of 0·20 to 0·40 upon those of solid girders satisfying the same conditions, see 119 to 135. This saving is due to the fact that, by taking precautions to ensure the rigidity of the struts, we may have girders of great height without having a too heavy vertical portion.

93. *Girders having Vertical Bars.*—If we suppose $\beta = 90°$ in the girder, Fig. 1657, with a load on the lower side, and express the bearing by N $\delta$ (N being even), we shall have *a girder with vertical braces*, which will weigh for each mètre

$$\frac{P}{l} = \frac{(p+p')\,t}{24\,N}\left\{\frac{l^2}{N^2\,h}\left[4\,N\,U\,(N^2-1) + 6\,N^2\,V + V\,(N^2-4)\,q\right] + (1+V)\left[6\,N^2 + (N^2-4)\,q\right]h\right\} + \Omega.$$

If, on the other hand, $\alpha$ be taken equal to 90°, we shall have *a girder with vertical struts*, weighing

$$\frac{P}{l} = \frac{(p+p')\,t}{24\,N}\left\{\frac{l^2}{N^2\,h}\left[4\,N\,U\,(N^2-1) + 6\,N^2 + (N^2-4)\,q\right] + (1+V)\left[6\,N^2 + (N^2-4)\,q\right]h\right\} + \Omega.$$

In one respect, this latter weight will be less than the preceding because the coefficient V affects fewer terms, but in another respect, $\Omega$ will be greater, for it must include the lengthening of the lower flange, which, according to theory, would have a total length of only (N − 2) $\delta$, whilst in practice it is absolutely necessary that it reach the abutments, even if the strain upon the extreme sections should be nul.

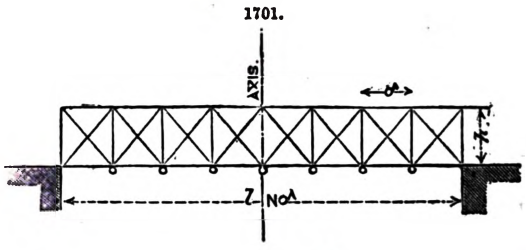
The other analogous cases in which N would be odd, or those in which the load would be applied to the upper part, will be easily calculated by the aid of the formulæ given, 39 to 62. But, as these girders with vertical bars are less advantageous than those having bars at an equal inclination, we shall not consider them further.

94. *Girders of Crosses, or Double Lattice.*—Girders of simple crosses, with or without vertical stays, should be considered as a double lattice, and may be calculated by imagining that they result from the juxtaposition of two simple lattices. Now in every multiple system in which several pieces simultaneously combine to resist a certain distortion which may be prevented by a single piece, there takes place a distribution of strains that it is not always easy to discover exactly when the conditions are complex; it may be computed, however, with some degree of certainty when we take care to render the conditions of strain equivalent or comparable. The general rule is that the various pieces should undergo equal proportional extensions, and that,

consequently, they distribute among each other the total strain proportionally to their sections; the strain a unit of section will be equal upon the several bars, with the exception of slight differences which may proceed from unequal tension given at the time of fixing. But in the case in which the strain acts by compression, the area of the sections does not alone influence the distribution, rigidity interferes, and if the forms of the sections are different, it is difficult to know to what degree a certain bar will yield, and another, and stronger one, to concentrate the load upon itself. The way to avoid these uncertainties is to make identical the multiple pieces which replace a single piece. However, with regard to multiple lattice-girders, this equal distribution must not be considered from bar to bar, but from system to system, because the pieces brought together being more or less distant from each other, the stress may vary from one to the other. If the whole is composed of $n$ simple lattices, each of them will be calculated as belonging to a girder supporting only the $\frac{1}{n}$ of the given load.

95. *Girders of Crosses and Vertical Rods.*—If we consider first a *girder of crosses and vertical rods, for a load applied to the lower part*, Fig. 1701, it is obvious that it may be resolved into two simple girders, one with vertical braces, the other with vertical struts, and the formulæ of which for the case of N even are given in 93. But the weight will be less than the arithmetical mean of these formulæ, for these vertical rods belonging at once to the two simple component lattices, are subject to a compressive strain on one side and to a tensile strain on the other; and the maximum strain upon them will be a constant tension $\frac{1}{2}(p+p')\delta$. The two end vertical bars must be excepted, the strain upon them, which is one of compression, being $\frac{1}{4}(N-1)\delta(p+p')$; so that these two bars alone make up the same theoretical weight as all the others, or rather more, for, resisting compression, they receive the coefficient V. We have thus as the total weight of the N + 1 vertical bars the value $\frac{1}{2}(N-1)(1+V)(p+p')\delta t h$, and the main weight of the lineal mètre of girder will be

1701.




$$\frac{P}{l}=\frac{(p+p')t}{24N}\left\{\frac{l^2}{N^2h}\left[4NU(N^2-1)+(1+V)\left(3N^2+\frac{N^2-4}{2}q\right)\right]\right.$$
$$\left.+(1+V)\left[3(N^2+4N-4)+\frac{N^2-4}{2}q\right]h\right\}+\Omega.$$

If the load be placed above the girder, the intermediate vertical bars will still support a maximum strain of $\frac{1}{2}(p+p')\delta$, but it will be one of compression which will necessitate the application of the coefficient of stiffness; and as to the two extreme bars, they, too, will be strengthened a little, for they will have to support directly the weight $\frac{1}{2}(p+p')\delta$ placed upright with the abutment, a weight which we had not to consider when the load was below, because it rested immediately upon the masonry without passing through the vertical bar. Consequently we shall have, for the case of a *load on the upper side*, and N even,

$$\frac{P}{l}=\frac{(p+p')t}{24N}\left\{\frac{l^2}{N^2h}\left[4NU(N^2-1)+(1+V)\left(3N^2+\frac{N^2-4}{2}q\right)\right]\right.$$
$$\left.+(1+V)\left(3N^2+\frac{N^2-4}{2}q\right)h+24NVh\right\}+\Omega.$$

*When N is odd*, we have for the case of a load on the lower side,

$$\frac{P}{l}=\frac{(N-1)(p+p')t}{24N}\left\{\frac{(N+1)l^2}{2N^2h}[8NU+(1+V)(6+q)]\right.$$
$$\left.+(1+V)h\left[12+\frac{N+1}{2}(6+q)\right]\right\}+\Omega;$$

and the changing of the load from the lower side to the upper will occasion an increase of expense, because the intermediate vertical bars will have to be stiffened, and the end bars will have the additional strain of a partial weight resting through them upon the abutment.

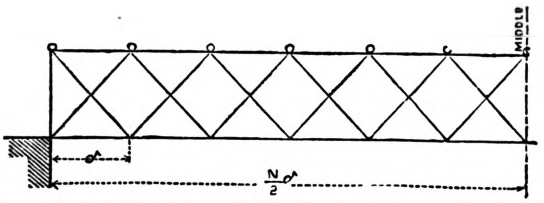
But we shall see presently that a saving may be effected by suppressing the intermediate vertical bars or rods, when possible; and if their presence is necessary, it will be for the purpose of affixing the cross-pieces, or for other purposes foreign to the resistance of the girder, so that it will be more logical to consider them as an accessory addition, their section being supposed as given according to the duty they have to fulfil (see 100).

96. The *wooden girders of Howe's system* have the form of girders of crosses with vertical rods; but an essential difference from the point of view of resistance is, that the wooden crosses, merely abutting the bearing-blocks, cannot resist by tension; under a given load, there is only one of the bars of each cross that resists, whilst the vertical rods, each composed of several smaller ones,

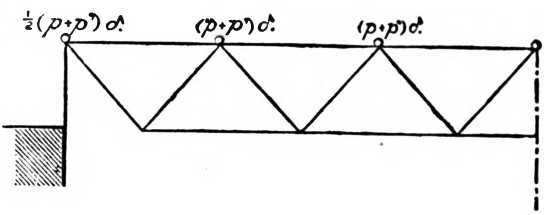
always take a tensile strain; the system resists as a simple yielding lattice, that is, its form changes according as the strain comes upon one or the other piece of each cross.

97. *Girders of Crosses without Vertical Rods.*—If we consider a *lattice of crosses without intermediate vertical rods*, loaded on the upper side, Fig. 1702, we see that it may be resolved into two simple systems given by Figs. 1703 and 1704. Now the system of Fig. 1703 corresponds to the case $\alpha = \beta$ in 53 by changing $\delta$ into $2\,\delta$, $m$ into $\frac{N}{4}$, and reducing the load by half. Besides this, we must add the two end vertical bars, the strain upon which is nearly $\frac{N}{4}(p+p')\,\delta$; they will weigh together $\frac{1}{4}(1+V)(p+p')\,l\,h\,t$, if we apply to them, instead o. V, the coefficient $\frac{1+V}{2}$, which

1702.

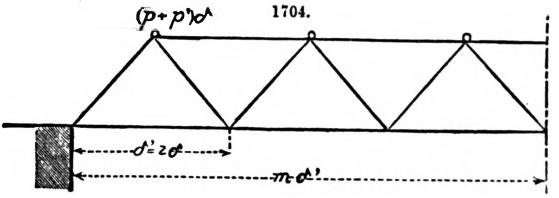



1703.




will simplify a little the general formula, and which is warranted by the fact that the theoretical resistance being considerable, there is no need of a large coefficient of stiffness; besides, the end vertical bars have already been taken into account by the fact that the total weight of the girder is obtained by multiplying the weight of the lineal mètre by the whole length and not by the bearing only.

1704.




The system of Fig. 1704 will come under the case of $\alpha = \beta$ of section 50, but only under the condition that the extreme weight be made equal to the other weights, instead of being $\frac{3}{4}$ only. On this hypothesis, the strain upon the $n$th strut or the $n$th brace will be $\frac{\delta'}{\sin.\alpha}\left[n\,p+\frac{(m+n)^2}{4m}p'\right]$, a value which extends to brace No. 0, as well as to the $n$th strut, and which supposes that the weights applied to the several summits are equal to $p\,\delta'$ or to $(p+p')\,\delta$, according to the case. The total weight of the oblique bars will consequently be $\frac{2m^2(p+p')\,\delta'\,h\,t}{\sin.^2\alpha}\left[1+\frac{2m^2+1}{12m^2}q\right]$ a formula in which $\delta'$ will be changed into $2\,\delta$, $m$ into $\frac{N}{4}$, and in which the load will be divided by 2. For the flanges of this figure, we must also, in the formulæ of 50, take into account the modification of the load in the extreme summit.

Adding together the weights of the two component lattices, and dividing by the bearing, we shall obtain as the weight of the lineal mètre of girder, Fig. 1702,

$$\frac{P}{\gamma}=\frac{1}{24}(p+p')\,t\left\{\frac{l^2}{N\,h}\left[4\,U.\frac{N^2-1}{N}+3(1+V)\left(1+\frac{N^2-4}{6N^2}q\right)\right]\right.$$

$$\left.+3\,h\,(N+2)(1+V)\left(1+\frac{N-2}{6N}q\right)\right\}+\Omega.$$

This formula obviously remains the same when the load is on the lower side instead of the upper. It supposes N even, but may also be applied approximatively for N odd; however, in this latter case, it is better to employ the formula in 99.

98. The point of view from which we have considered the question in the preceding section offers the difficulty of a certain complication in calculating the strains upon the various pieces, and as a multiple system leaves the distribution of the loads arbitrary, we take advantage of it in this case to adopt a more convenient process. In the preceding method a brace bore the same strain as one of the struts to which it was fixed at the extremities, but now we shall suppose that both bars of a cross are subject to a strain $\frac{F}{2\sin.\alpha}$, F being the stress in the interval occupied by the cross. It follows from this that in the two flanges, the sections or divisions situate perpendicularly to each other will support also the same strain (on account of the condition of equilibrium relative to the horizontal projections of the forces), which was not the case on the preceding hypothesis; this strain is calculated by the moment of rupture with respect to the centre of the cross; the total weight, however, of the two flanges together remains the same as before. As to the lattice, not including the end vertical bars, it is represented by $\frac{(1+V)\,h\,t}{2\sin.^2\alpha}\,\Sigma\,F$, an expression in which $\Sigma\,F$ denotes the sum of the absolute maxima strains in the successive intervals, for the whole bearing, the value of which sum is given in 6 for the two cases of N even or odd. Adding the end vertical bars, the

strain upon which is $\frac{1}{4}(N+1)(p+p')\delta$, including the weight they directly support, and which will, therefore, weigh together $\frac{N+1}{4N}(p+p')tlh$, we obtain as the total weight of the lattice per lineal mètre, in the case in which N is even, the following expression:

$$\frac{1}{8}(1+V)(p+p')t\left\{\left(N+2\frac{2}{N}+\frac{N^2-4}{6N}q\right)h+\left(1+\frac{N^2-4}{6N^2}q\right)\frac{l^2}{Nh}\right\},$$

which differs only by a slight increase of the end vertical bars, from the value which enters into the formula of the preceding section. This difference proceeds from the fact of our having, in 97, attributed to these bars a mean strain between the cases of a load on the upper and a load on the under side.

99. For N odd, we obtain the following weight of the lineal mètre of girder, the latter being calculated in the manner we have just alluded to:

$$\frac{P}{l}=\frac{N^2-1}{24N}(p+p')t\left\{\frac{l^2}{N^2h}\left[4UN+(1+V)\left(3+\frac{1}{2}q\right)\right]+3h(1+V)\left(\frac{N+1}{N-1}+\frac{q}{6}\right)\right\}+\Omega.$$

This formula may be admitted for a load on the upper or on the under side, for the situation of the load occasions but a slight difference in the weight of the end vertical bars.

On comparing the formulæ of the lattice composed of crosses, with those of girders of simple triangles with bars at an equal inclination, we see that the difference consists essentially in this fact, namely, that with crosses the weight of the lattice is modified as if the length of the intervals $\delta$ had been doubled, and, consequently, their number reduced by one-half. We ought, in general, to adopt that one of the two systems which brings the inclination of the bars nearest to 45°.

100. *Vertical Rods considered as a supplementary term.*—On comparing girders of crosses without intermediate vertical rods with those which possess them, we find that these latter have an excess of weight represented by these additional rods, which thus form, from the point of view of the resistance of the girder, a superfluous addition. Their use is, in fact, limited to distributing the load among all the summits both at the top and at the bottom, instead of affecting directly only one of the flanges; but there is no advantage in this, because the horizontal space between the points of application of the strains remains the same.

But these rods are useful in certain cases, chiefly in girders loaded on the lower side, to stay the vertical portion and maintain its perpendicularity. We are justified, therefore, in considering this kind of girder; only, as the reason for introducing intermediate vertical rods is foreign to the theoretical resistance, we shall reckon them as a supplementary addition, represented for the mètre of girder by the term $\frac{rNh}{l}$, in which $r$ denotes the weight of the lineal mètre of rod. These rods, which usually need be placed upon one side only of the vertical portion of the girder, may have the form of a single T composed of a projecting strip of plate iron and two angle-irons. If, for instance, for heights of 2 to 5 mètres, these sections are composed in the following manner:—

| | | | | |
|---|---|---|---|---|
| Height $h$ of the girder .. .. .. .. | | $2^m$ | $3^m$ | $4^m$ | $5^m$ |
| Mean section of a vertical rod .. | Projecting plate of .. | $130/10^{mm}$ | 200/10 | 260/10 | 260/10 |
| | Two angle-irons of .. | 80/80/10 | 80/80/10 | 110/70/10 | 130/75/12 |

we shall conclude that $r$ may be represented by $8(2+h)$, and, consequently, the additional term for vertical rods will be $\frac{8Nh(2+h)}{l}$. The rest of the girder will be regarded as expressed by the formulæ for lattices composed of crosses without intermediate vertical rods.

101. *Examples.—First Example.—Girder of Crosses without intermediate Vertical Rods*, Figs. 1705 to 1707.—Data: $l=24^m$, $\delta=3^m$, $N=8$, $h=2^m\cdot50$, $p=1000^k$ (the girder itself weighing 300), $p'=2400^k$ (one rail), $p+p'=3400$, $q=0\cdot706$.

Following the method of calculation set forth in 98, the strains upon the successive divisions of the flanges will be, reckoning from the middle, 94·9, 82·6, 58·2, 21·4 tons; those upon each of the two bars forming the successive crosses will be 8·2, 14·1, 20·6, 27·9 tons; and that upon the end vertical bars 23 tons.

The braces are, like the struts, made of double angle-irons, in order that the rigidity of the compressed bar may be identified with that of a cross composed of four angle-irons by joining the sections of the brace and the strut. For a bar in the middle, for example, the reduced thickness of a cross of four angle-irons of 70/70/8 millimètres will be $0^m\cdot08$; the ratio of the free length to this thickness is $\frac{2\cdot80}{0\cdot08}$ or 35, which requires a coefficient of stiffness = 1·56. With the section adopted, this coefficient is 1·55, a value which is all the more sufficient because the rivetings at the extremities of the bar amount to a joining of the metal.

The fixing of the extreme bars requires the application of joint-plates to give the rivets a double resisting section: we obtain by this means twenty sections, which is amply sufficient.

Direct calculation gives for the whole girder:—

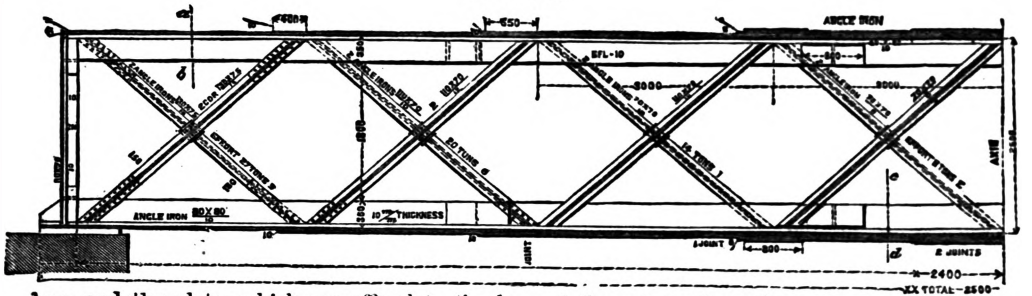
| | | | | |
|---|---|---|---|---|
| Flanges | Angle-irons and vertical ribs with their joint-plates .. | 2750 | $5600^k$ | $7500^k$ |
| | Horizontal plates .. .. .. .. .. .. .. .. .. | 2850 | | |
| Bars | Braces and struts .. .. .. .. .. .. .. .. .. | 1550 | $1900$ | |
| | Joint-plates and filling-plates affixed to the bars at the point where they cross .. .. .. .. .. .. .. | 140 | | |
| | Two end vertical bars .. .. .. .. .. .. .. .. | 210 | | |

Say 300 kilogrammes per mètre of girder.

The flanges weighing 224 kilogrammes the mètre of girder, whilst the formula in 97 gives them 167 U, we have U 1·34.

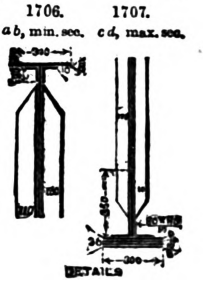
The bars amount to 1900 kilogrammes, 140 of which are for the special pieces for fixing the end

1705.
Scale 0·01.



bars and the plates which are affixed to the bars at the points where they cross each other; but these 140 kilogrammes are nearly compensated by the saving resulting from the fact that the bars have not quite their theoretical length; so that we may suppose Ω nul, and take then V = 1·30, at which we arrive from a comparison of the weight $\frac{1900}{25}$ = 76 kilogrammes, resulting from the calculation, with that of 33 (1 + V), furnished by the formula.

1706. 1707.
*a b*, min. sec. *c d*, max. sec.



If we admitted 1 + V = 1·95 + 0·15 *h*, the best height would result from the equation 120 = (2·65 + 0·408 *h*) *h*², and would be about 5 mètres, a great value which proceeds from the extreme lightness of the lattice; but it is prudent not to exceed the height of 4ᵐ·50, near which we cannot practically reduce the section of the flanges.

A greater diminution of the height is warranted by the small variation of the weight and by the advantage of diminishing the importance of the exterior tie-pieces. Yet, if the height allowed be unlimited, we shall do well to take a height of 3 mètres instead of 2·50 as in the plan.

If the load were doubled and made 6800 kilogrammes the mètre, everything included, it would be easy to reduce U to 1·25, and V to 1·15, even if the height were carried up to 3ᵐ·50.

102. *Second Example.—Girder of Crosses and without Vertical Rods, for a Tubular Bridge of 72 mètres span*, Figs. 1708 to 1717.—Data: $l = 72^m$, $\delta = 8^m$, N = 9, $h = 9^m$, $p = 3000^k$ (the girder itself weighing 1700), $p' = 4000^k$, $p + p' = 7000^k$, $q = 0·5714$.

When one line of rails only is loaded, $p'$ amounts to only 3000 kilogrammes, which will allow us to reduce by $\frac{1}{7}$ the weight of the girder if we do not object to raise R to 7 kilogrammes the square millimètre for the very exceptional case of two heavily-laden trains crossing the bridge at the same time.

The strains upon the portions of the flanges, reckoning from the middle to the ends, are:—498, 473, 398, 274, and 100 tons; the strains upon each of the two bars of the crosses = 24, 52, 82, 115, and 150 tons; the end vertical bars support 112 tons.

In the elevation of this girder and some others we have been obliged to exaggerate slightly the thicknesses of the horizontal plates of the flanges in order to render the arrangement of them perceptible.

The struts have a double T section, offering a great moment of resistance in the direction normal to the vertical portion of the girder. In the plane of this vertical portion, the free length being only half, the rigidity is sufficient with the sections adopted. We might, if necessary, take the sections of a hollow form, as in Figs. 1690 to 1700.

The braces are composed of two equal and parallel pieces enclosing the strut, and are fixed externally to the vertical ribs of the flanges; but the two bars of the middle cross are identical and in the form of a double T.

In fixing the end bars, the double rib allows us to place eighty rivets of 0ᵐ·025; so that it is useless to double the shearing sections. The thickness of 0ᵐ·012 given to the ribs renders tearing away impossible.

The gussets at the point where the bars cross each other serve not only to connect the brace and the strut, but as joint-plates for these pieces. But for several bars at the end, composed of two thicknesses of plate, this gusset can cover the joint of only one plate; the joint of the second plate is then made to fall in another place where it has special joint-plates. The angle-irons of the bars may be continuous throughout the length.

The following is the result of the calculation:—

| | | | | | |
|---|---|---|---|---|---|
| Flanges | Angle-irons | principal | 10505 | 87840, say 879000ᵏ | 122500ᵏ |
| | | border | 2835 | | |
| | Double vertical ribs | | 22380 | | |
| | Special joint-plates for angle-irons, and so on | | 3550 | | |
| | Horizontal plates with their joint-plates | | 48120 | | |
| | Plates between the vertical ribs, at the ends of each cross-girder | | 450 | | |
| Bars | Struts and braces | | 27630 | 34000 | |
| | Two end vertical bars | | 4270 | | |
| | Plates at the point of crossing and joint-plates | | 2100 | | |
| Hand-rails | | | | 600 | |

It follows from this that the mean weight of the lineal mètre of girder will be 1630 kilogrammes.

We might make up an additional term $\Omega$ by taking, in the flanges, the border angle-irons which do not enter into the theoretical resistance, and the plates at the ends of the cross-girders; and in the bars, the plates at the points of crossing and the joint-plates; to this might be added the hand-rails. But we should have to deduct the saving in the length of the bars, which does not reach the theoretical length; and this saving more than compensates the weight of the light pieces of railing. The plates upon the bars and their joint-plates may enter into V, for these pieces are a function of $h$ in this sense that a less height would allow us to suppress the joint-plates and reduce the dimension of the plates. The accessories of the flanges may be introduced into the coefficient U. From this point of view, we shall regard $\Omega$ as nul, U $= 1{\cdot}36$, and V $= 1{\cdot}25$.

1708.

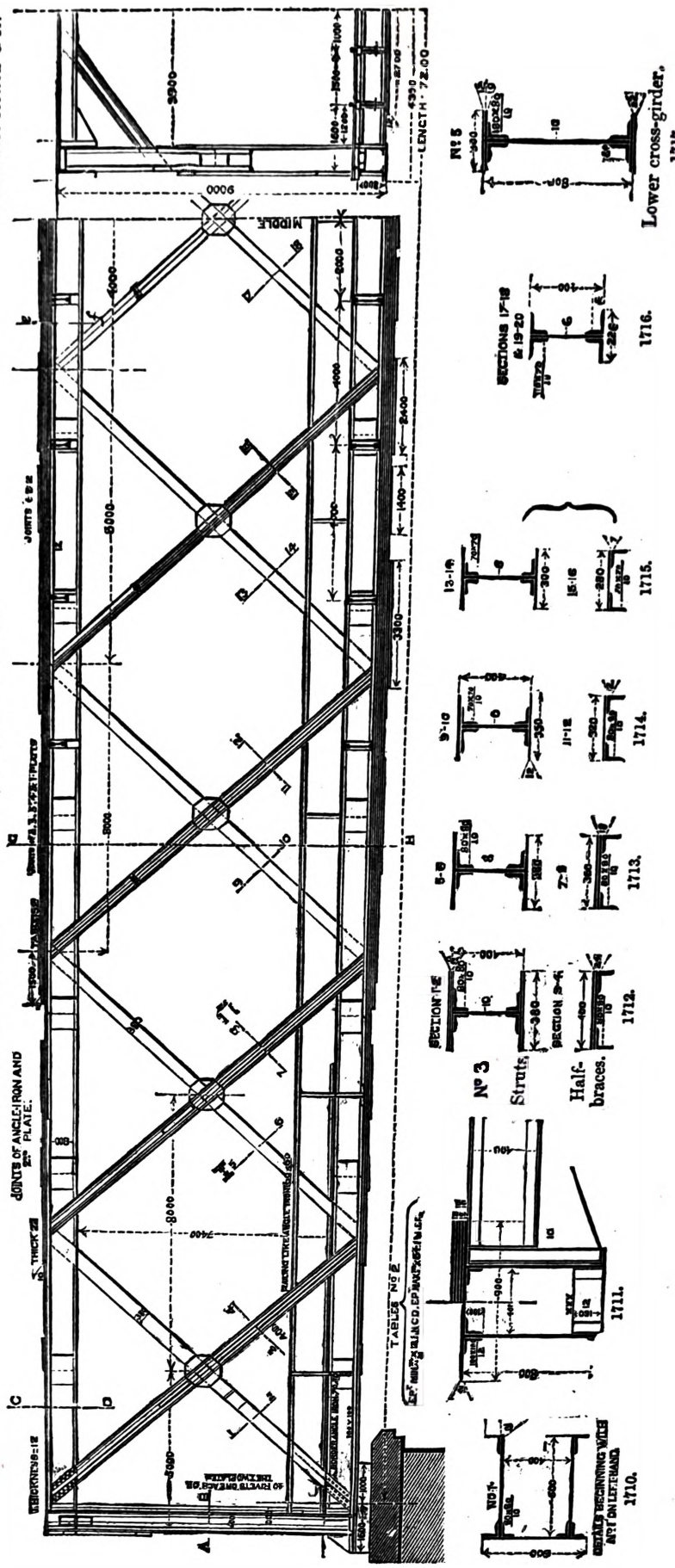
If we admit that when near the most economical height, $1 + V$ increases according to the law $1 + V = 1{\cdot}35 + 0{\cdot}10\ h$, and that U is reckoned as only $1{\cdot}06$, according to the rule given in 64, the best height will result from the equation $0{\cdot}807\ h^3 + 5{\cdot}45\ h^2 = 2726$, and will be 13 mètres. Indeed we shall then have V $= 1{\cdot}65$, U $= 150$, and the weight of the girder a mètre will be brought down to 1510 kilogrammes, whilst for $h = 9$, V $= 1{\cdot}25$ and U $= 1{\cdot}36$, the formula gives 1626 kilogrammes.

103. *Third Example.—Girder of Crosses and with Vertical Rods, of* 40 *mètres span*, Figs. 1718 to 1725.—Data: $l = 40^m$, $\delta = 4^m$,

1709.

Transverse section G H.

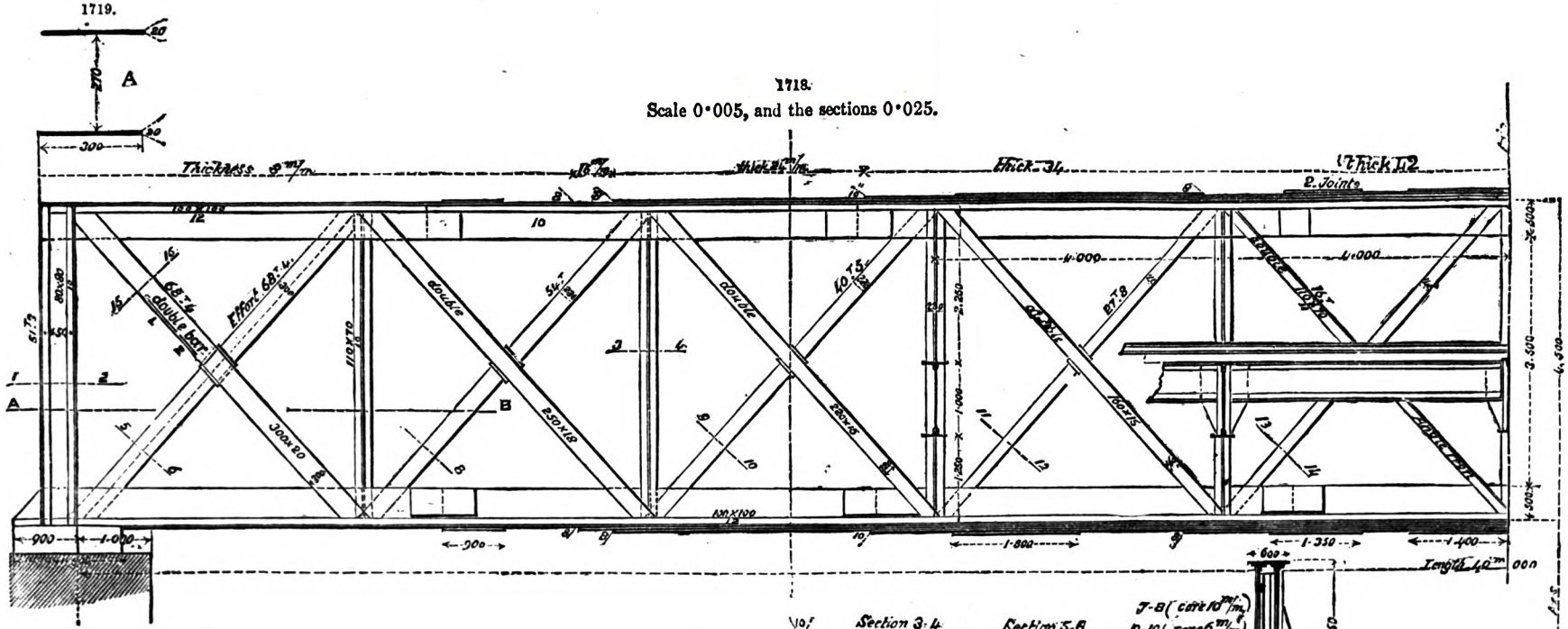
Scale $0{\cdot}005$ for the elevation and transverse section, $0{\cdot}025$ for the details.



1719.

1718.

Scale 0·005, and the sections 0·025.



$N = 10$, $h = 4^m \cdot 50$; $p = 2500^k$, $p' = 3200$ (one line of rails loaded), $p + p' = 5700^k$, $q = 0 \cdot 56$.

In the exceptional case in which both lines are simultaneously loaded at the rate of 4300 kilogrammes a mètre each, the bridge will be subjected to a strain of about $7^k \cdot 2$, and this may be allowed.

Successive strains upon the portions of the flanges = 248, 228, 188, 127, and 46 tons;

Successive strains upon the bars = 16, 28, 41, 54, and 68 tons;

Strain upon the end vertical bars = 51 tons.

In order to fix properly the struts in the double I form, whose greatest stiffness is in the direction normal to the vertical portion of the girder, double vertical ribs to each flange have been adopted, as in the preceding example. The braces are of flat, equal and parallel bars enclosing the struts, except in the two middle crosses, in which the flat bars are replaced by two angle-irons of 110/70/11 millimètres, because, in certain positions of the load, these braces may have to bear slight compression.

The bars bearing the greatest strain are fixed without having recourse to double shearing sections, for 20 or 24 rivets may be placed upon each of the two ribs, and this is amply sufficient.

The intermediate vertical rods serve for affixing the cross-girders. The following is the result of calculation:—

| | | | | |
|---|---|---|---|---|
| Two flanges | Angle-irons and vertical ribs with their joint-plates .. | 13300 | 23500 | 34000$^k$. |
| | Horizontal plates and their joint-plates .. .. .. | 10200 | | |
| Lattice .. | Oblique bars (including $100^k$ for plates) .. .. .. | 7200 | 10500 | |
| | Two end vertical bars with their gussets .. .. .. | 1450 | | |
| | Nine intermediate vertical rods .. .. .. .. .. | 1850 | | |

Thus the girder weighs 815 kilogrammes per mètre, its whole length being $41^m \cdot 80$.

The term $\Omega$ will be nul, for the bar-plates amounting to only 100 kilogrammes, do not even compensate the saving upon the length of the bars.

The flanges amount, according to calculation, to 563 a mètre, and according to the formula $435\,U$; hence $U = 1 \cdot 30$.

The oblique bars = 207 according to calculation, and $90\,(1 + V)$ according to the formula. Therefore $V = 1 \cdot 30$.

Supposing $1 + V = 1 \cdot 75 + \frac{1}{8} h$, and expressing the vertical rods by an additional term $\frac{8 N h (2 + h)}{l}$, (100), the most economical height will be $5^m \cdot 90$, which will allow us to construct a tubular bridge, and to suppress the intermediate vertical rods. Thus for bridges of two girders of more than 40 mètres span, we may adopt the tubular system in preference to girders loaded on the lower side, if we desire to obtain greater stability in the girders.

104. *Tables of the Weights of Girders.*—The best height to adopt is an implicit function of the load in virtue of the coefficient V, so that the height of heavy girders may be increased a little.

If for girders lightly loaded we suppose $h = 0 \cdot 11\, l$, $U = 1 \cdot 40$, $V = 1 \cdot 35$, and for girders heavily loaded $h = \frac{1}{8} l$, $U = 1 \cdot 35$, and $V = 1 \cdot 30$, these coefficients will allow us to suppose $\Omega$ nul, and by applying the general formulæ (97 and 99), we may construct the Tables on p. 827, giving the values of $\frac{P}{(p + p')\, l^2}$; that is, the weight of the lineal mètre of girder will be found by multiplying the numbers of the Tables by $(p + p')\, l$.

The least expense corresponds to $N = 8$ in the first Table, and to $N = 7$ in the second. These values give, having regard to the heights adopted, directions to the bars a little less than 45° upon the horizontal, since the Tables decrease with N.

If there be intermediate vertical rods, they must be added as we have seen in 100, which is equivalent to adding to the numbers in the Tables the quantity $\frac{8 N h (2 + h)}{(p + p')\, l^2}$.

105. Supposing loads similar to those which were taken for girders of triangles (92), the weight of the girders themselves only being slightly reduced in a few cases, and taking the same values of N, namely, 7 for a span of 20 mètres, 8 for spans of 30 to 60 mètres inclusive, 9 for 70 mètres, and 10 for 80 mètres, we shall have the following approximative weights for girders without intermediate vertical rods.

| Spans .. .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres. 80 |
|---|---|---|---|---|---|---|---|
| Weight of the lineal mètre of girder carrying one rail ($h = 0 \cdot 11\, l$) .. .. .. .. .. | Kilos. 260 | Kilos. 385 | Kilos. 520 | Kilos. 650 | Kilos. 780 | Kilos. 940 | Kilos. 1140 |
| Weight of the lineal mètre of girder carrying one line of rails $\left(h = \frac{1}{8} l\right)$ .. .. .. .. | 445 | 670 | 880 | 1100 | 1310 | 1590 | 1900 |

It will be seen that in large spans these girders of crosses without vertical rods offer a small saving over those of simple triangles (92), because the supposed values of N allow of the bars being placed nearer the inclination of 45°, and because in the double lattice the strains upon the

TABLE X. A.—Value of $\frac{P}{(p+p')\,l^2}$ for girders lightly loaded.

| | N = 5. | N = 6. | N = 7. | N = 8. | N = 9. | N = 10. | N = 11. | N = 12. | N = 13. | N = 14. | N = 15. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $q =$ 0·40 | 0·003674 | 0·003645 | 0·003623 | 0·003617 | 0·003622 | 0·003630 | 0·003649 | 0·003667 | 0·003694 | 0·003718 | 0·003750 |
| 0·50 | 0·003689 | 0·003657 | 0·003636 | 0·003629 | 0·003634 | 0·003643 | 0·003662 | 0·003680 | 0·003707 | 0·003732 | 0·003764 |
| 0·60 | 0·003703 | 0·003669 | 0·003649 | 0·003641 | 0·003647 | 0·003655 | 0·003675 | 0·003693 | 0·003721 | 0·003745 | 0·003778 |
| 0·70 | 0·003718 | 0·003682 | 0·003661 | 0·003653 | 0·003659 | 0·003667 | 0·003688 | 0·003706 | 0·003734 | 0·003759 | 0·003793 |
| 0·80 | 0·003732 | 0·003694 | 0·003674 | 0·003665 | 0·003672 | 0·003679 | 0·003700 | 0·003719 | 0·003748 | 0·003773 | 0·003807 |

TABLE X. B.—Value of $\frac{P}{(p+p')\,l^2}$ for girders heavily loaded.

| | N = 5. | N = 6. | N = 7. | N = 8. | N = 9. | N = 10. | N = 11. | N = 12. | N = 13. | N = 14. | N = 15. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $q =$ 0 40 | 0·003210 | 0·003193 | 0·003187 | 0·003191 | 0·003208 | 0·003225 | 0·003254 | 0·003279 | 0·003315 | 0·003346 | 0·003385 |
| 0·50 | 0·003224 | 0·003205 | 0·003199 | 0·003203 | 0·003220 | 0·003238 | 0·003267 | 0·003293 | 0·003329 | 0·003360 | 0·003400 |
| 0·60 | 0·003237 | 0·003216 | 0·003212 | 0·003214 | 0·003233 | 0·003250 | 0·003280 | 0·003306 | 0·003342 | 0·003374 | 0·003415 |
| 0·70 | 0·003250 | 0·003228 | 0·003224 | 0·003226 | 0·003245 | 0·003262 | 0·003293 | 0·003319 | 0·003356 | 0·003388 | 0·003430 |
| 0 80 | 0 003264 | 0 003239 | 0 003236 | 0·003238 | 0·003258 | 0·003274 | 0·003306 | 0·003332 | 0·003370 | 0·003402 | 0·003445 |

struts and braces are less, and, therefore, the several parts may be fixed without the addition of supplementary pieces.

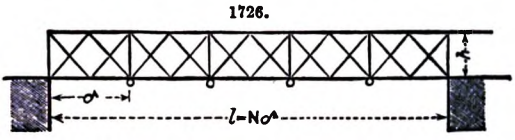
106. For girders with vertical rods calculated as in 100, the Table will become on the hypothesis of the same heights, although there may be occasion to reduce them a little in this case:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Spans .. .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres. 80 |
| Weight of the lineal mètre of girder { carrying one rail .. .. | Kilos. 285 | Kilos. 420 | Kilos. 565 | Kilos. 700 | Kilos. 840 | Kilos. 1020 | Kilos. 1235 |
| { „ one line of rails | 475 | 720 | 940 | 1170 | 1390 | 1690 | 2020 |

being weights differing but little from those of girders of simple triangles (92).

107. *Double Crosses.*—In cases of limited height, or in those of small girders, if we happen to have $h < \frac{\delta}{\sqrt{2}}$ we may place two crosses in an interval $\delta$ comprised between two successive points of application of the load. In this case, the weight of the diagonals will be modified, $\sin.^2 \alpha$ being changed into $\frac{1}{2} \sin.^2 \alpha'$, $\alpha'$ representing the greater inclination obtained by the doubling of the crosses. The flanges depend only on the distance apart of the loaded points; the vertical rods, if there are any, will be placed square with the cross-girders, in every second cross, Fig. 1726.

1726.




Confining ourselves to the case of N odd, the weight of the mètre of girder may be computed by the formula

$$\frac{P}{l} = \frac{(N^2-1)(p+p')\,t}{48\,N}\left\{\frac{l^2}{N^2\,h}\left[8\,N\,U + 3\,(1+V)\left(1+\frac{1}{6}\,q\right)\right] + 12\,h\,(1+V)\left[\frac{N+3}{N+1}+\frac{1}{6}\,q\right]\right\} + \Omega,$$

when the load is placed upon the lower part; and by

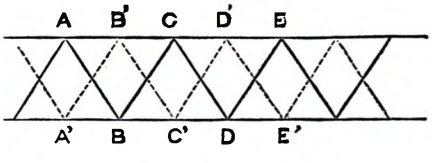
$$\frac{P}{l} = \frac{(N^2-1)(p+p')\,t}{48\,N}\left\{\frac{l^2}{N^2\,h}\left[8\,N\,U + 3\,(1+V)\left(1+\frac{1}{6}\,q\right)\right] + 12\,h\left[\frac{4\,N\,V}{N^2-1} + (1+V)\left(1+\frac{1}{6}\,q\right)\right]\right\} + \Omega,$$

if the load is on the upper part. The coefficient V is applied to the end vertical bars as well as to the other bars under compression.

108. *Multiple Lattice-girders.—General Observations.*—A multiple lattice may usually be considered as resulting from the superposition of several simple lattices, at least if we omit to consider the connection at the points where they cross each other. The component simple lattices may be of different systems, as it happened in the case of girders of crosses; sometimes, in such cases, certain bars participate simultaneously in the composition of two elementary lattices; and if they are acted upon on one side by a force of compression and on the other by a force of tension, their resulting maximum strain may be limited to a small value, as in the case of vertical rods considered in section 95.

We are now about to consider exclusively another kind of multiple lattice, resulting from the union of several simple lattices, identical in form, but placed one before another. Thus, in Fig. 1727, the system A B C D is a simple lattice, but we shall form a double one by superposing the parallel lattice A′ B′ C′, and this duplication will enable us to distribute the load applied to the girder over a double number of points, without subjecting the portions of the flanges to a deflecting strain. The load may be applied to all the summits or only to some of them. But even if all the loaded summits should belong exclusively to one of the elementary lattices, all the bars will take part in the resistance, for in virtue of the rigidity of the portions of the flanges a parallelogram such as B C E D cannot be distorted by the lengthening or shortening of the bars B C, D E, without producing a change in the intermediate bar C′ D′. Thus it is usual to calculate first the strains in a simple system as A B C D, and then to divide them equally among the whole of the bars. The flanges are regarded as loaded in a continuous manner.

1727.




The connection at the points of crossing enables a bar to receive variable strains at the same instant in its several subdivisions, and the vertical portion of the girder thus possesses a certain moment of resistance. But these secondary considerations are never taken into account.

The theoretical weight of a multiple lattice must, therefore, be obviously the same as that of a simple lattice the bars of which have the same inclination. But in practice each system has its advantages and its disadvantages, and may modify the expense in one direction or in another. By multiplying the bars we incur excesses of section, because the theoretical strains become very

small and would require dimensions which the importance of the girder would not allow; the plates, too, on the points where the bars cross each other increase in proportion. On the other hand, a multiple lattice may always be traced near 45°, whatever the interval between the cross-girders may be, whilst with simple bars we may be obliged to have recourse to less advantageous inclinations. From the point of view of rigidity, if the multiplicity of the points of crossing offers the advantage of subdividing the bars into portions of inconsiderable length, on the other hand the sections decrease, the vertical portion of the girder acquires a tendency to twist like a thin sheet of iron, and we are obliged to remedy this disadvantage by the addition of stiffening vertical rods. At the ends of the girder, a certain number of the elementary lattices terminate by fragments of bars which are fixed at different points in the height of the end vertical bar. This bar would, therefore, have a tendency to bend if the precaution were not taken of replacing it by a broad piece of solid plate iron stiffened by projecting ribs.

It seems, therefore, preferable not to multiply beyond a moderate degree the systems of lattice, but to construct them of bars possessing the greatest possible rigidity. It is only in cases in which the rivetings become difficult that we should have recourse to the multiple system, for then the bars, being weakened, may be fixed by a very small number of rivets. This is the principal consideration which should decide the degree of multiplicity.

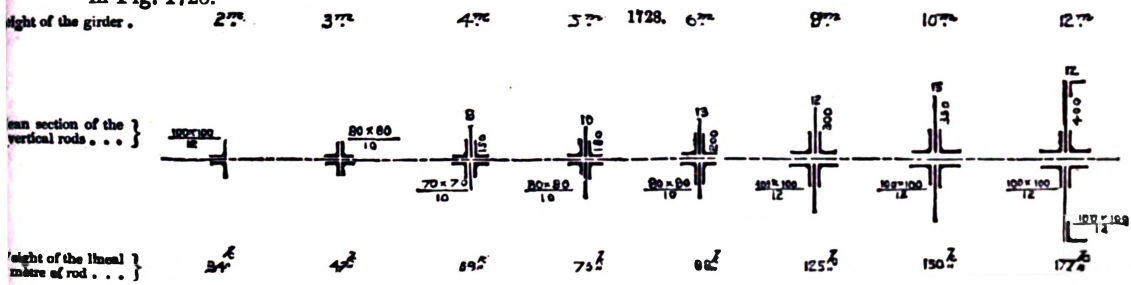
As to the comparative security of simple and multiple lattices, provided the joints and rivetings are equally solid, they may be regarded from this point of view as equal. If the bars were of cast iron or of wood, it might be objected that a defect in a single piece would be sufficient to ruin a simple system, whilst in a multiple system the resistance never falls upon a single piece. But in bridges of malleable iron, this objection would be specious, for a bar should have such a section that it may be composed, in almost all cases, of several pieces riveted together; consequently, a defect in one of the pieces will be protected by the other sound parts, and it may happen that all the elementary pieces may be defective without the whole breaking, if the defective portions are isolated by the rivetings; the only result in such a case being a greater strain upon the sound portions than was anticipated. In those parts in which the strains are inconsiderable, a multiple system will offer in general a great excess of resistance, but it will be at the price of an excess of material, and we might, if we chose, increase the sections in a simple system to obtain an equal additional security.

109. If the inclination of the bars remains constant when the height varies, the lattice will have, theoretically, a nearly constant weight; in order that the flanges may be supported at the same intervals, the multiplicity of the lattice must increase with the height. Indeed, even when the general rigidity of the vertical portion of the girder resides chiefly in the addition of projecting ribs, we must reckon upon a surplus expense for the local rigidity of the several portions of the compressed bars, and for other conditions which must be fulfilled, principally not to reduce the sections below a certain minimum, not to make a continuous variation from bar to bar, but only by successive groups, to take into account in certain cases the weakening occasioned by the rivet-holes, and so on. We may affect the whole of the lattice with a coefficient V, but in analogy with the notations employed for girders of triangles or crosses, in which V was specially applied to the struts, we will denote the general coefficient by $\frac{1+V}{2}$, (82).

110. The stiffening vertical rods may serve also for affixing the cross-girders, and the vertical cross-bracing. Their section increases with the height, but may be taken nearly constant with the load in the ordinary cases of railway bridges, for they will thus add, as they should do, a relative increase of strength which will be the greater as the lattice becomes weaker and more liable to distortion. For the same reason they may be made to vary but little in the several points in the length of a given girder.

Instead of placing only one vertical rod in a line with each cross-girder, it may be advantageous, if the distances $\delta$ are great, to have two for each interval, placing them alternatively on each side of the vertical portion of the girder when nothing prevents. Or we may place principal rods in a line with the cross-girders, and other weaker rods in the middle of the intervals.

Let us suppose adopted as a mean, for the case of one rod to the interval $\delta$, the sections given in Fig. 1728.




The weights given by this figure may be put into the formula $15\,h$, so that the weight of the rods a lineal mètre of girder will be represented by $\frac{15\,h^2}{\delta}$.

111. *Formulæ of Weight.*—The flanges will make up a weight $\frac{(p+p')\,l^2\,t\,U}{5\,h}$ a lineal mètre of girder, regarding the load as continuous. The bars at 45° give $\frac{1+V}{24}(p+p')(6+q)\,l\,t$

The end vertical bars transmit to the abutments the strains upon the bars which are fixed at different points in their length; their section should theoretically increase from the top to the bottom, and as their mean compression is equal to half the reaction of the abutment, that is to $\frac{1}{4}(p+p')\,l$, their total weight will be $\frac{1}{2}(p+p')\,t\,l\,h$, say $\frac{1}{2}(p+p')\,t\,h$ per mètre of girder. But, in practice, this is insufficient, and, as we shall see by the examples hereafter, it is necessary to add to each extreme bar two vertical stiffening rods similar to those described in the preceding section; we thus obtain at once the necessary rigidity, and an increase such that the section will be everywhere superior to the theoretical value, and will, therefore, not need to vary from the bottom upwards.

This addition of four vertical rods will give, to a mètre of girder, a term $\frac{60\,h^2}{l}$, admitting the sections of Figs. 1729 to 1731; and if there are already intermediate rods to the number of $\frac{l}{\delta}-1$, the term including all these additions will be $15\,h^2\,\frac{l-3\,\delta}{l\,\delta}$

To sum up, we shall have the weight of the lineal mètre of a lattice-girder with vertical rods, by the formula

$$\frac{P}{l}=(p+p')\,\frac{l^2\,t\,U}{6\,h}+\frac{1+V}{24}(p+p')\,(6+q)\,l\,t+\frac{1}{2}(p+p')\,t\,h+15\,h^2\,\frac{l+3\,\delta}{l\,\delta}+\Omega.$$

112. Suppose $1+V=a+b\,h$, this formula becomes

$$\frac{P}{l}=(p+p')\,\frac{l^2\,t\,U}{6\,h}+\frac{a}{24}(p+p')\,(6+q)\,l\,t+\frac{1}{2}(p+p')\,t\left[1+\frac{b\,l}{12}(6+q)\right]h+15\,h^2\,\frac{l+3\,\delta}{l\,\delta}+\Omega.$$

If the ratio $\frac{h}{\delta}$ were regarded as constant, and we made $\frac{h\,(l+3\,\delta)}{(p+p')\,l\,\delta\,t}=\theta$, the most advantageous height would be $h_1=l\sqrt{\frac{U}{3+\frac{1}{4}\,b\,l\,(6+q)+90\,\theta}}$, and it would reduce the weight of the mètre of girder to the minimum value,

$$\frac{P_1}{l}=(p+p')\,l\,t\left\{\frac{1}{3}\sqrt{U\left[3+\frac{1}{4}\,b\,l\,(6+q)+90\,\theta\right]}+\frac{a}{24}(6+q)\right\}+\Omega.$$

If, instead of $h_1$ we adopted a different height $h=\kappa\,h_1$, the term of the radical in the preceding expression would be multiplied by $\frac{\kappa^2+1}{2\,\kappa}$.

But usually $\delta$ is a fixed quantity, unconnected with $h$, and the most economical height is then determined by an equation of the third degree.

113. When the lattice-bars have sufficiently rigid forms to allow the vertical rods to be suppressed, the weight of the girder will be found by the formula

$$\frac{P}{l}=\frac{1}{2}(p+p')\,t\left[\frac{U\,l^2}{3\,h}+\frac{1}{12}(1+V)(6+q)\,l+h\right]+\frac{60\,h^2}{l}+\Omega.$$

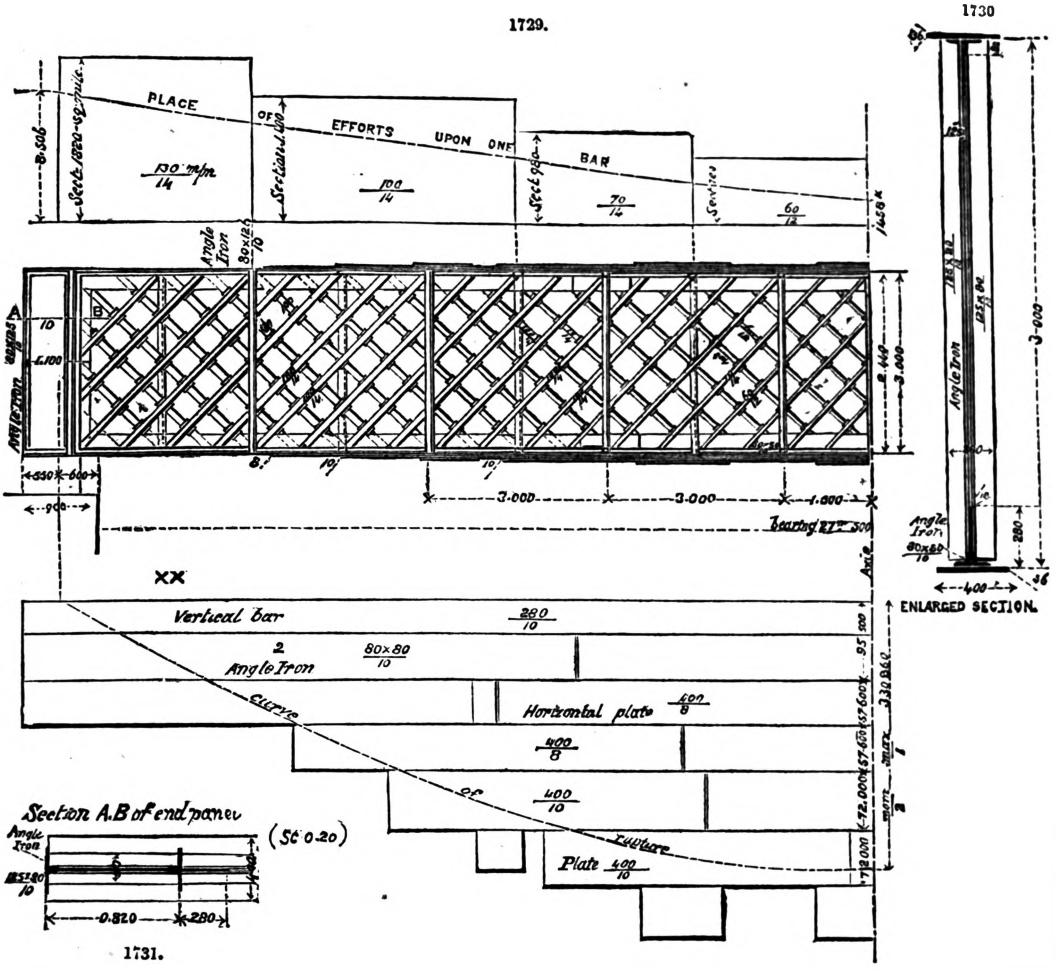
114. *Examples.—First Example.—Flat-bar Lattice-girder with Vertical Rods*, Figs. 1729 to 1731.—Data: $l=27^{m}\cdot50$, $\delta=3^{m}\cdot00$, $p=1100^{k}$, $p'=2400^{k}$, $p+p'=3500^{k}$, $q=0\cdot686$.

The flat form which the bars have in this case is the least favourable to rigidity, but it enables us to place the vertical rods in a projecting position upon each side of the vertical portion of the girder, without weakening in any part the section of the bars. The lattice is multiplied eight times; the bars of which it is composed vary from 130/14 millimètres to 60/12, both for compression and tension; for here, the bars being weak, it is well to give, even to those subject to tension, an excess of section on account of the loss occasioned by the rivet-holes. In a line with the cross-girders, at intervals of 3 mètres, the lattice is enclosed by vertical rods formed of two angle-irons of 80/120/10 millimètres, one on each side; and in the middle of the intervals there are single rods formed of one angle-iron. The weight of all these rods to each lineal mètre of girder is 42 kilogrammes; this result agrees with the formula which, for $\delta=3$, gives $\frac{15\,h^2}{\delta}=45$, the weight 42 kilogrammes, not including certain pieces used to fill up the hollows in fixing the rods. The figure contains plans or diagrams of the resistance of the flanges and the lattice the former shows the arrangement of the horizontal plates and their joint-plates. In the diagram of the lattice the ordinates of the curve represent the strain upon a bar to the scale of $2\frac{1}{2}$ millimètres a ton or the necessary theoretical section, abstracting the rigidity to the scale of $1\frac{1}{2}$ millimètre a square centimètre; the broken line is the locus of the sections really adopted, or the strains to which the bars would be liable if they could be subjected to a stress of 6 kilogrammes a square millimètre.

The weight of a girder is made up of the following quantities:—

| | | | |
|---|---|---|---|
| Flanges, including joint-plates .. .. .. .. .. .. | 7600$^{k}$ | 12970, say 13000$^{k}$, or 455 a mètre. | |
| Bars at 45° (including 270$^{k}$ for plates) .. .. .. .. .. | 3300 | | |
| Vertical rods (including 70$^{k}$ for filling) .. .. .. | 1210 | 2070 | |
| End vertical pieces .. .. .. .. .. .. .. | 860 | | |

1729.




1730

1731.

The formula of 111 will be made to agree with the results by supposing $U = 1{\cdot}39$, $V = 2{\cdot}16$, and $\Omega = 12$ kilogrammes say the 0·026 of the total weight. The term $\Omega$ includes the plates upon the bars at the points of crossing and the filling used in fixing the vertical rods. The value of V is high, because the tension-bars have been increased, as well as those subject to compression; the discontinuous variation of section by groups of bars is also a source of loss. Yet, notwithstanding this high value of V, the rigidity of the lattice is to us less satisfactory than in the girders of the following examples, in which the bars have a better form. If the load were double, V could be reduced easily to 1·90. The vertical rods agree with the hypotheses of the formula by taking $\delta = 3$ mètres, that is, by considering the single rods as borrowed from the double or principal rods, which are to an equal extent weakened.

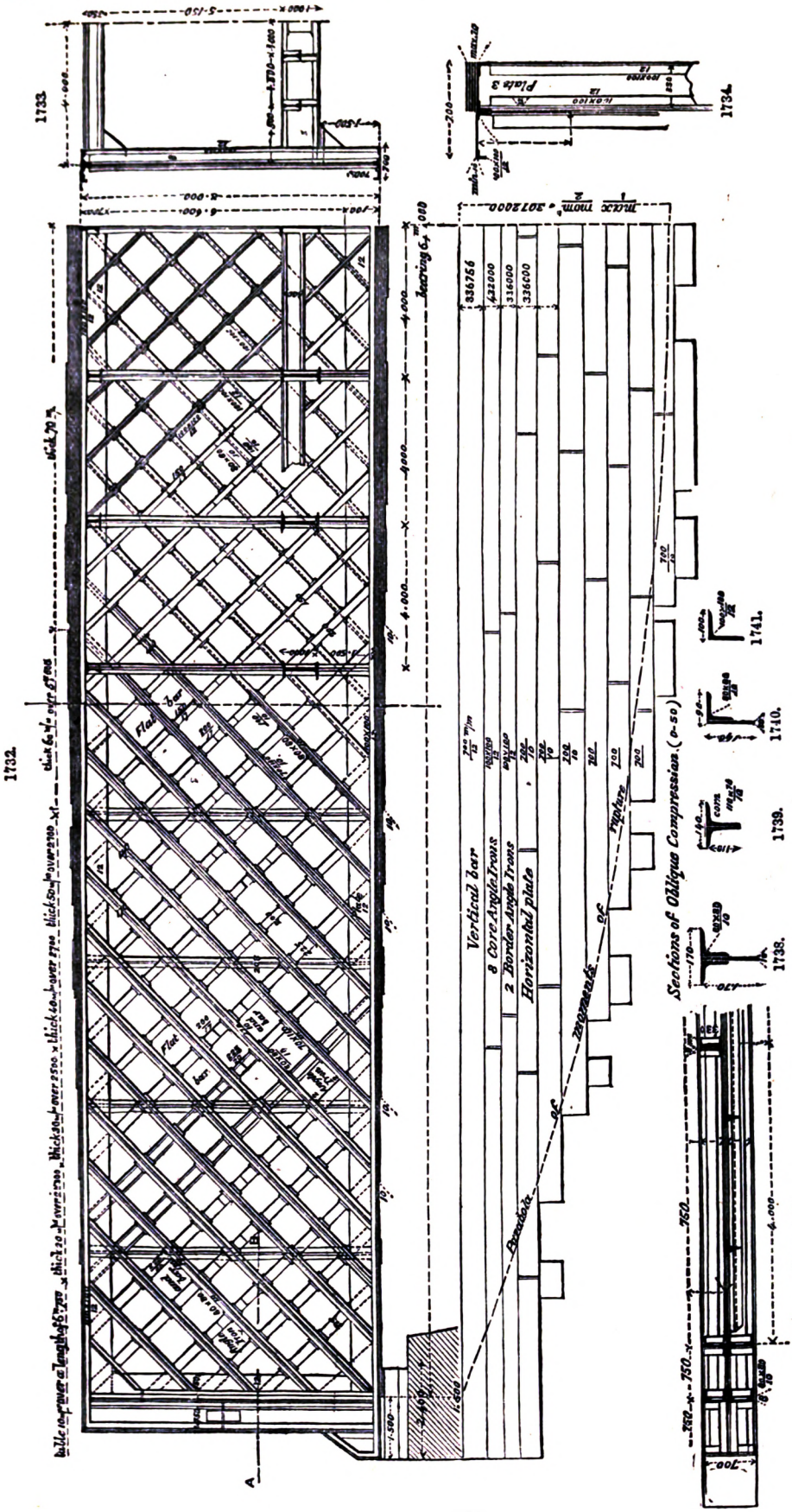
The end solid vertical pieces are also conveniently represented by the formula, for the term $\frac{1}{2}(p + p')\,l\,t\,h$ gives 188 kilogrammes, four rods give 60 $h^2$ or 540, and the 860 kilogrammes of the calculation will be completed by the fact that the total weight of the lattice proper is calculated for the whole length of girder instead of for the bearing only.

If we suppose $V + 1 = 2{\cdot}35 + 0{\cdot}27\,h$, the most advantageous height will be obtained from the equation $608 = (11{\cdot}69 + 13{\cdot}27\,h)\,h^2$, whence $h =$ about $3^m{\cdot}30$. Reckoning in this case $U = 1{\cdot}42$, the minimum weight will be 452 kilogrammes, including 12 kilogrammes for $\Omega$.

It will be seen that the reduction of the height to 3 mètres has not increased the weight in any sensible degree.

115. *Second Example.—Girder with Rigid Struts and with Vertical Rods*, Figs. 1732 to 1741.—Data: $l = 64^m$, $\delta = 4^m$, $h = 8^m$, $p = 3000^k$, $p' = 3000^k$ (for the case of a single line loaded with $4000^k$), $p + p' = 6000^k$, $q = 0{\cdot}50$.

Here we adopt a mixed system, better than the preceding: the vertical rods are placed upon one side only of the lattice, which enables us to place on the other side oblique bars with projecting ribs, and arranged to resist compression; in the middle only, a few braces are made of angle-iron, because in certain cases they may be subject to compression. These angle-irons are then cut away in a line with the vertical rods; but their resisting section remains intact in the portions of their length where they have of themselves to resist compression, producing a deflecting strain.


1732.
1733.
1734.
Plate 3
Vertical bar
8 Core Angle Irons
2 Border Angle Irons
Horizontal plate
Flat bar
Parabola of moments of rupture
Sections of Oblique Compression (0-50)
1738.
1739.
1740.
1741.
Plan A B.
1737.

This system is of itself sufficiently rigid to allow the adoption of a more open lattice than in the case of flat bars; and, in fact, notwithstanding the considerable height of the girder, we have multiplied it only ten times. The vertical rods weigh only 145 kilogrammes a mètre of girder, instead of 240 kilogrammes, which the formula of 111 would allow. This gain is due to the rigidity which the struts already possess.

The following is the result of direct calculation:—

| | | | | |
|---|---|---|---|---|
| Flanges | Angle-irons and vertical ribs with their joint-plates .. .. .. .. | 20000$^k$ | 55500 | 96000, say 1435$^k$ a mètre of girder. |
| | Horizontal plates with their joint-plates .. | 35500 | | |
| Bars at 45°, including 1000$^k$ for plates and joint-plates .. .. | | 25200 | 34500 | |
| Vertical rods, with their filling .. | | 9300 | | |
| End solid vertical pieces .. .. .. .. | | 6000 | | |

These quantities correspond with U = 1·25, V = 1·80, Ω = 15 (for plates on the bars), or 0·01 of the total weight.

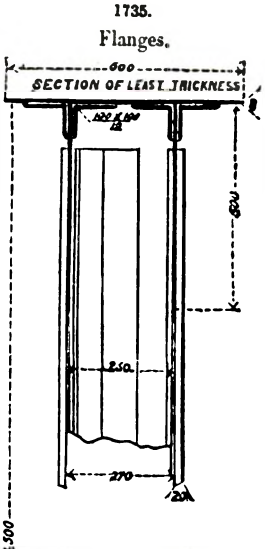
For the end vertical pieces, the term $\frac{1}{2}(p + p')\, l\, h\, t$ gives 2000 kilogrammes, four vertical rods according to the formula will amount to 3840; these two amounts added to the weight furnished by the hypothesis that the lattice extends along the bearing upon the abutments, will give more than the 6000 kilogrammes obtained by direct calculation.

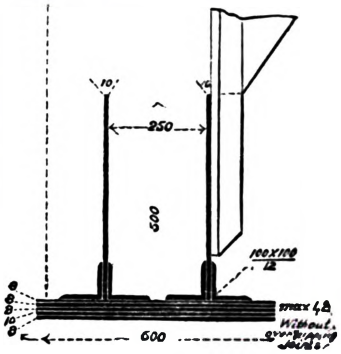
If the height be increased, and the same degree of multiplicity, and the same distance between the vertical rods retained, the latter being suitably strengthened, V will vary but slowly on account of the rigid form of the compression-bars. Suppose, for example, $1 + V = 2{\cdot}40 + 0{\cdot}05\, h$, $U = 1{\cdot}06 + 0{\cdot}024\, h$, Ω = 15, and reduce to $10\, h^2 \frac{l + 3\delta}{l\delta}$ the term for the rods, the weight of the mètre of girder with the present data, but for an indeterminate height, will be

$$\frac{P}{l} = 5645\,\frac{1}{h} + 10{\cdot}66\, h + 2{\cdot}97\, h^2 + 468.$$

The minimum is for $h$ = about 9$^m$·30, and its value is 1430 kilogrammes, whilst for the height of 8 mètres the same formula gives 1450 kilogrammes. The height may, therefore, be again slightly reduced, without much disadvantage: taking it at 7 mètres, for example, the weight would not exceed 1495 kilogrammes a mètre.

1735.




1736.

116. *Third Example.—Rigid Lattice-girder without Vertical Rods*, Figs. 1742 to 1747.—Data: $l$ = 40$^m$, $h$ = 4$^m$·50, $p$ = 2200$^k$ (the girder itself weighing 900), $p'$ = 3800$^k$ (the contiguous line only being loaded at the rate of 4300$^k$ a mètre), $p + p'$ = 6000, $q$ = 0·633.

The lattice is only sixfold. All the bars are of a rigid form, and the connection at the points of crossing utilize the rigidity of the braces in favour of the struts. The bars on one side of the lattice keep the same direction throughout the length of the girder, so that no projection is cut away. Calculation gives

| | | | | |
|---|---|---|---|---|
| Flanges | Vertical ribs and angle-irons with their joint-plates | 7500$^k$ | 24400 | 37200$^k$, say 890 a mètre of girder. |
| | Horizontal plates with their joint-plates .. .. | 16900 | | |
| Lattice-bars (including 300$^k$ for gussets at the points of crossing) .. | | 10300 | | |
| End vertical pieces .. .. .. .. .. .. .. .. .. .. | | 2500 | | |

These quantities correspond with U = 1·26, V = 1·90, and Ω = 7$^k$, say the 0·008 of the total weight; V might be reduced if, instead of having only four series of sections for the bars, we varied them in a continuous manner.

If, when $h$ varies, we suppose $U = 1{\cdot}06 + 0{\cdot}046\, h$, and $1 + V = 1{\cdot}55 + 0{\cdot}30\, h$, the formula of 113 will become with the other data of the present example, $\frac{P}{l} = \frac{2205}{h} + 29{\cdot}8\,.\,h + 1{\cdot}5\, h^2 + 236$.

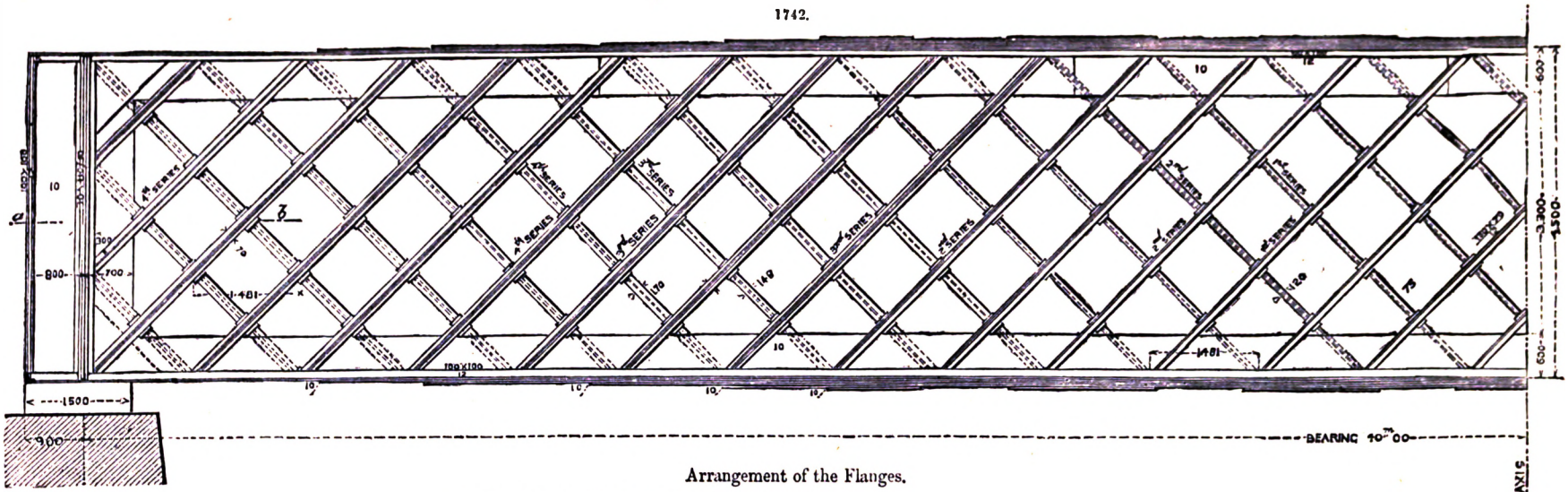
The minimum for a height of 6$^m$·70 will be 831 kilogrammes a metre, instead of 890 as for the girder in the plan.

117. *Tables of Weights.*—We will suppose generally the following loads, which differ from those of 92 only by a small increase in the weight of the girders:—

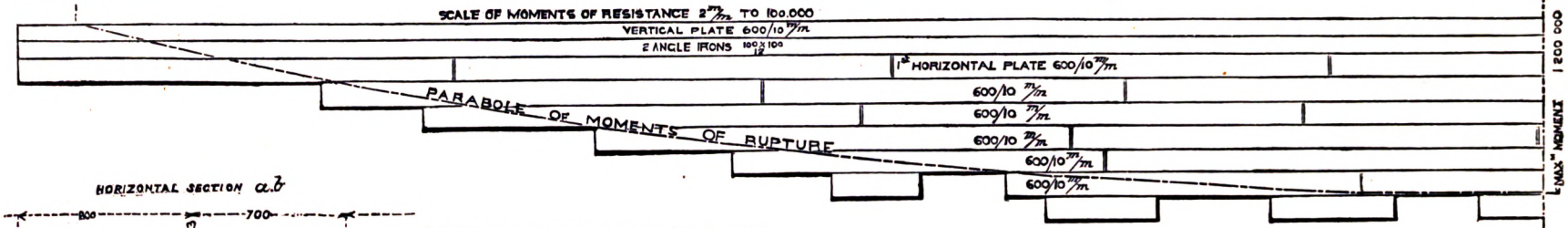
| | *Girders carrying one rail.* | | | | | *Girders carrying two rails.* | | |
|---|---|---|---|---|---|---|---|---|
| $l$ = | 20$^m$ | 60$^m$ | 80$^m$ | .. | .. | 20$^m$ | 60$^m$ | 80$^m$ |
| $p + p'$ = | 3600$^k$ | 3600$^k$ | 4000$^k$ | .. | .. | 7000$^k$ | 6900$^k$ | 7600$^k$ |
| $q$ = | 0·695 | 0·556 | 0·500 | .. | .. | 0·714 | 0·580 | 0·576 |

Let us suppose again for girders carrying one rail, $h = 0{\cdot}11\, l$, U = 1·40, V = 2·20, Ω = 10 and for girders loaded with two rails, $h = \frac{1}{8}\, l$, U = 1·30, V = 1·90, and Ω = 15. The formula of 113 will give us the following Table.

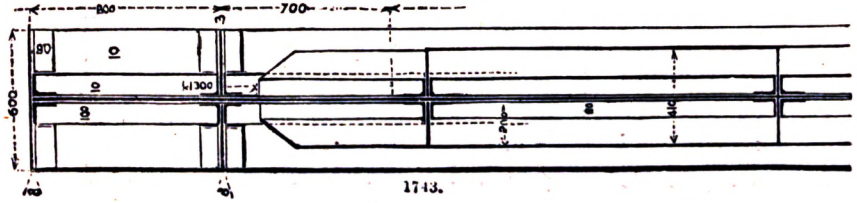
1742.




Arrangement of the Flanges.

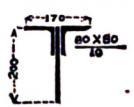



HORIZONTAL SECTION a.b



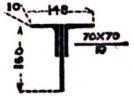

1743.

4th SERIES OF BARS.




1744.

3rd SERIES




1745.

2nd SERIES

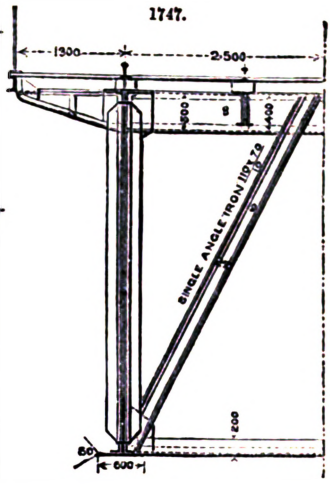
1746.

1st SERIES MIDDLE

1746.

*Weight a lineal mètre of rigid multiple lattice-girders.*

| Span .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres. 80 |
|---|---|---|---|---|---|---|---|
| Girders carrying only one rail .. | Kilos. 315 | Kilos. 465 | Kilos. 610 | Kilos. 760 | Kilos. 910 | Kilos. 1125 | Kilos. 1335 |
| Girders carrying two rails .. | 510 | 750 | 990 | 1230 | 1465 | 1800 | 2135 |




Generally girders carrying two rails may be relieved of a portion of their load, if we allow a strain greater than 6 kilogrammes the square millimètre for the accidental case of two heavily-laden trains crossing the bridge at the same time.

The weights in this Table exceed those of girders with simple crosses (105), but are considerably below those for girders with a solid rib (129, 130, 133).

118. For lattice-girders of flat bars, with stiffening vertical rods, V can receive hardly any reduction, and the weight will increase by the addition of the rods. The latter form a rather arbitrary element; but on the hypotheses made in section 110, and by giving to $\delta$ a value varying from 2 to 5 mètres, according as the span varies from 20 to 80 mètres, we may admit the following figures, which suppose the adoption of the same heights as in the preceding section

*Weight of the mètre of a flat lattice-girder, stiffened by vertical rods.*

| Span .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres. 80 |
|---|---|---|---|---|---|---|---|
| | Kilos. | Kilos. | Kilos. | Kilos | Kilos. | Kilos. | Kilos. |
| Girders carrying only one rail .. .. .. .. | 350 | 530 | 710 | 890 | 1075 | 1320 | 1570 |
| „ „ two rails.. .. .. .. .. | 560 | 835 | 1115 | 1400 | 1675 | 2055 | 2435 |

We may, in the case of vertical rods, adopt heights a little less; but the weights will change only in a very small degree.

When the vertical rods are on one side only of the lattice, as in Fig. 1732, we may make half the bars at 45° rigid, and reduce in consequence the weight of the rods. The value of the girder will then be between those of the Tables in 117 and 118.

119. *Solid Girders.—Vertical Portion.*—The solid rib or web is exclusively employed for all kinds of girders of small dimensions, such as cross-girders and minor longitudinal girders. We have already given in 13 to 19 the rules applicable to these kinds of pieces.

We purpose now to examine girders of greater importance, for there is an appreciable interest, in this case, in submitting the plates of the vertical portion and the pieces which give it rigidity to a more minute discussion.

Denoting the height of the girder by $h$, and the variable thickness of the vertical portion by $e$, the theoretical volume of the latter will be expressed by $h \int e\,dx$, or by $\frac{1}{R_1} \int F\,dx$, according to the value of $e$ given in section 1. Replacing the area $\int F\,dx$ of the locus of the stress by the value in section 4, we shall have for the whole bearing: theoretical volume of the vertical portion $= \frac{1}{4R_1}(p+p')\left(1+\frac{1}{6}q\right)l^2$.

120. Comparing this expression with the theoretical volume of a multiple lattice at 45° without vertical rods, namely, $\frac{1}{4R_1}(p+p')\left(1+\frac{1}{6}q\right)(1+V)l^2$, we see that if $R_1$ were equal to R, the solid rib would have only a volume equal to that of the braces in a multiple lattice, or equal to half the volume of this lattice, supposing V reduced to unity.

We may conceive this fact by imagining the solid rib split into a great number of strips at 45°, placed so as to form the tension-bars of a multiple lattice: these bars in mutual contact will press each other laterally, and these pressures will render useless the addition of struts; for a rod subject to a tensile strain at the rate of R kilogrammes the unit of section, may also be compressed at the same coefficient normally to its length without the resulting pressure exceeding R in any direction.

But the coefficient $R_1$ of resistance to shearing force is usually taken equal to 4000000, whilst R rises to 6000000. The vertical portion, or rib, will therefore already reach the $\frac{3}{4}$ of the theoretical volume of a lattice at 45°. Besides this, the joint-plates and the pieces added to give rigidity, joined to the circumstance that the vertical portion itself cannot be strictly reduced everywhere to the theoretical thickness, render it in reality more expensive than the lattice, at least when the girder acquires a certain importance. Stiffening pieces, or the application of a sufficient coefficient $V_1$, are, it is true, necessary for a multiple lattice also; but if it be a very open one, and bars of a proper form be adopted, a certain fraction of the required rigidity will be already furnished by the theoretical volume, which will reduce in an equal degree the supplementary additions.

The continuity of the rib, or vertical part, prevents it from resisting exactly as a lattice; the strains, too, vary in a continuous manner from one point to another, instead of remaining constant throughout the length of the imaginary strips of which we have spoken. If the plate were very thin, compression would produce corrugations, while tension would be concentrated in certain points; the plate would wrinkle in directions near 45°, and the wrinkles thus formed would show the direction of the greatest tensile strains, or the positions of the braces in the lattice offering the greatest resistance, which might be cut out of the vertical plate, having regard to the mode of loading.

This continuity of the vertical portion allows it to be introduced into the calculation of the moment of resistance; but generally it will raise it only by a very small value, especially as the thickness is reduced to a minimum precisely in the middle, where the moment of resistance should be great. It is, therefore, not necessary to compute exactly the part taken by the vertical portion in the moment of resistance; it is well even to undervalue it slightly, on account of the influence of the joints, which diminish the resistance a little.

121. *Flanges.*—The variable section $s$ of the flanges is given by the following equation, which expresses the equality of the moment of rupture M to the moment of resistance: $M = R\,h\left(s + \frac{F}{6\,R_1}\right)$, see section 14. Substituting for M and F the values given in section 4, we deduce

$$s = \frac{1}{2}(p+p')\left(\frac{x(l-x)}{R\,h} - \frac{l-2x}{6\,R_1}\right) - \frac{p'x^2}{12\,R_1}.$$

The maximum for $x = \frac{1}{2}$ will be $s_1 = \frac{(p+p')\,l^2}{8\,R\,h} - \frac{p'\,l}{48\,R_1}$.

From this maximum value, the theoretical section $s$ decreases as the ordinate of a parabola as we approach the abutments; it becomes nul at the point where the vertical portion alone possesses a sufficient moment of resistance to be in equilibrio with the moment of rupture, and beyond this it becomes negative even. But it cannot in reality be thus: not only must $s$ not become nul, it must not even descend below a certain minimum $s_2$ which may be fixed in each case. If $x_2$ is the abscissa (reckoned from the abutment) which gives to $s$ this value $s_2$, the total volume of the flanges will be $2\left[l\,s_2 + \frac{2}{3}(s_1 - s_2)(l - 2x)\right]$.

122. But this formula would be inconvenient, and it is better to consider simply the volume of the two flanges as equal to $\frac{4}{3}\,l\,s_1$, that is, as if the section varied parabolically from $s_1$ in the middle to 0 at the extremities, and the coefficient U may serve to correct nearly the divergence between the form thus conceived, and the one occurring in practice. And, as the least thickness of the vertical rib in the middle is never less than $0^m{\cdot}006$, we may compute its moment of resistance for this thickness, neglecting the surplus if the plate is stouter; $s_1$ will then have the value $\frac{(p+p')\,l^2}{8\,R\,h} - 0{\cdot}001\,h$, and consequently, total weight of the two flanges

$$= \frac{t\,l\,U}{3}\left(\frac{(p+p')\,l^2}{2\,h} - 0{\cdot}004\,R\,h\right).$$

123. *Accessories.*—To complete the weight of the girder, there yet remain to be computed the accessories of the vertical portion, namely, 1, the excess of material occasioned by the fact that the thickness varies by redans or gradations and not in a continuous manner, and also by the fact that it cannot descend in any part below a certain minimum, $0^m{\cdot}006$ for instance; 2, the joint-plates of the rib; and 3, the pieces intended to give it rigidity.

In girders heavily loaded, we may suppose that the redans and the surplus thickness, indispensable in the middle, are equivalent to an extra continuous thickness of about $0^m{\cdot}0027$ applied to the whole vertical rib.

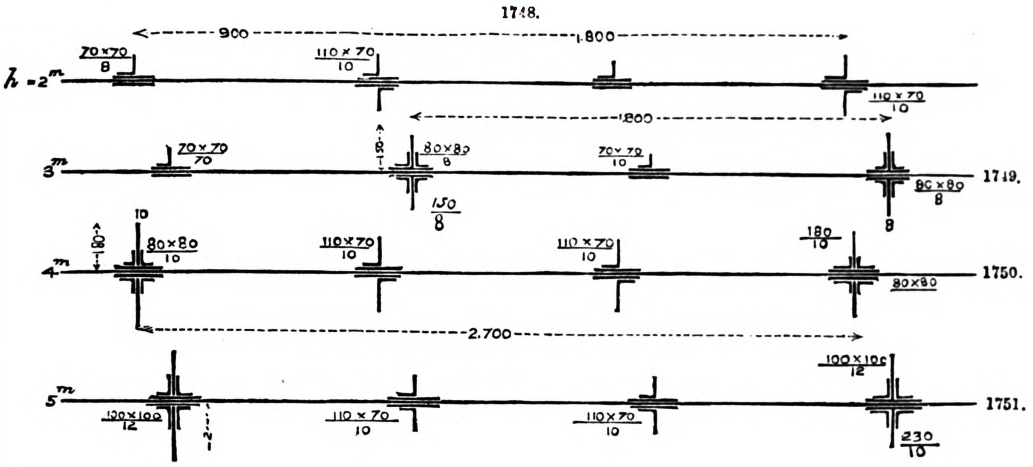
124. As to the *joints*, they may be placed widely apart when the height of the girder does not exceed the breadth of the iron plates, and this is one of the causes which make the solid rib economical for small girders. But when the height becomes considerable, a case which we are now discussing, we must not reckon upon distances greater than $0^m{\cdot}90$ between the successive joints. In order that the rivets may offer a double shearing section, for the purpose of reducing the breadth of the joint-plates, the latter are composed of double plates placed on each side of the vertical rib; these plates will nearly always be of $0^m{\cdot}006$, for a less thickness is seldom employed in the construction of bridges, and on the other hand that of $0^m{\cdot}006$ is sufficient when the rib consists of stout plate of $0^m{\cdot}012$. The breadth of the joint-plates may, at least over a certain portion of the girder, be limited to $0^m{\cdot}160$, placing only one row of rivets upon each side of the joint. But if the stress reaches a high value near the supports, it may be necessary to place a double row of rivets, and to increase the breadth of the joint-plates to $0^m{\cdot}300$, so that there may always be on each side of the joint a number of rivets at least equal to $\frac{F}{2\,R_1\,\sigma}$, F being the stress, $R_1$ the resistance to a shearing force, and $\sigma$ the section of a rivet. If, as a mean, we reckon $0^m{\cdot}200$ for the breadth of the joint-plates, they will be equivalent to an extra continuous thickness of $0^m{\cdot}0027$, which, added to that of the preceding section, gives $0^m{\cdot}0054$.

This amount may be retained for girders lightly loaded; for if on the one hand the breadth of all the joint-plates is reduced to $0^m{\cdot}160$, which produces an extra thickness of only $0^m{\cdot}0022$; on the other hand, in small girders especially, calculation will assign thicknesses too far below the limit.

125. The pieces added to give rigidity are usually vertical and are applied to the joint-plates;

they thus form vertical rods, which are made use of in fixing the cross-girders, or brackets. Their section is not determined by rigorous laws, it is necessary only that their projecting ribs should increase with the height, to ensure rigidity. It is often advantageous to increase those situate in a line with the cross-girders at the expense of the intermediate ones. Let us, for example, suppose adopted, for heights of 2 to 5 mètres, the arrangements shown by Figs. 1748 to 1751, which gives the horizontal section of a certain length of vertical rib.

1748.




With these forms, the angle-irons and transverse plates, not including the joint-plates, will weigh $12\,h$ kilogrammes a square mètre of vertical rib, and this is equivalent to a reduced thickness equal to $0{\cdot}00154\,h$. We will put it at $0{\cdot}002\,h$, to be able to increase the rigidity of the vertical rib again towards the ends. This value is considered as applicable to strong as well as to weak girders; it will constitute for these latter an addition of strength relatively greater, as, indeed, should be the case, for it is the weak vertical ribs which are most liable to twist. We may, within certain limits, modify the distance of the vertical stiffening pieces apart by modifying inversely their section. Sometimes we shall do well to fix the transverse plates by means of a single angle-iron, and to rivet to the exterior edge a second angle-iron. The intermediate stiffening pieces will have a U form instead of a T, and the border angle-iron will give a gratuitous increase of rigidity.

126. *Formula and Table of Weights for Solid Girders.*—Adding the weight of the theoretical vertical rib (119) and that of the flanges (122), reduced to the lineal mètre of girder, as well as the accessories equivalent to extra thicknesses of $0^{m}{\cdot}0054$ (124) and of $0{\cdot}002\,h$ (125), we obtain the following formula as the expression of the weight of the girder a lineal mètre:

$$\frac{P}{l} = \frac{1}{6}(p+p')\,l\,t\left\{\frac{U\,l}{h} + \frac{3}{8}(6+q)\right\} + h\,(42{\cdot}12 - 8000\,t\,U + 15{\cdot}6\,h).$$

As $q$ has but a small influence, we may substitute for it the value $0{\cdot}60$ from which it will generally not differ much, and we shall then have

$$\frac{P}{l} = (p+p')\,l\left\{0{\cdot}0002167\,U\,\frac{l}{h} + 0{\cdot}0005363\right\} + h\,(42{\cdot}12 - 10{\cdot}4\,U + 15{\cdot}6\,h).$$

Substituting for the coefficient U in this expression the value assigned to it in 64 and seeking the condition of the minimum of expense, we find that the most advantageous height $h_1$ must satisfy the equation: $0{\cdot}23\,(p+p')\,l^2 = (31510 + 31200\,h)\,h^2$.

127. The loads $p+p'$ do not vary much with the span, because the moving load $p'$ decreases, while the dead weight of the girder increases. For spans of 20 and 55 mètres, we may adopt the following loads, according as the girder is to carry one or two rails:—

| | | Girders carrying | |
|---|---|---|---|
| | | One Rail. | Two Rails. |
| | | kilos. | kilos. |
| 20 mètres span .. | Exterior dead weight .. .. | 700 | 1400 |
| | Weight of the girder .. .. | 400 | 600 |
| | Moving load $p'$ .. .. .. | 2500 | 5000 |
| | Total load $p+p'$ .. .. | 3600 | 7000 |
| 55 mètres span .. | Exterior dead weight .. .. | 700 | 1400 |
| | Weight of the girder .. .. | 1300 | 2000 |
| | Moving load .. .. .. .. | 2000 | 4000 |
| | Total load .. .. .. | 4000 | 7400 |

Substituting these quantities in the equation of the preceding section, we find that, for 20 mètres span, the most economical height will be $1^m \cdot 90$ if the girder supports only one rail, and $2^m \cdot 45$ if it supports two rails. For 55 mètres span, we obtain respectively $4^m \cdot 20$ and $5^m \cdot 20$.

Thus, for girders the least loaded, the ratio of the most advantageous height to the span would vary from 0·095 in small spans, to 0·076 in long ones; and for heavy girders from 0·12 to 0·095. We may alter these heights a little without the weight changing sensibly, and it will often be advantageous to reduce them, either to lessen the vertical cross-bracing and cross-ties if the bridge is loaded on the upper side, or to increase the stability if the girders are loaded on the lower side, or again, to satisfy conditions of limited thickness. In the following Tables we give heights reduced by about $\frac{1}{10}$.

128. It remains to compute U, which, according to 66, may be expressed by $1 \cdot 06 + 4 \cdot 80 \frac{R s_0 h}{(p+p')l^2}$, or $1 \cdot 06 + \frac{1 \cdot 10 R s_0}{h(31510 + 31200 h)}$ by replacing $\frac{h^2}{l^2}$ by the value obtained from the equation which ends section 126. From this U may be regarded as independent of the load; it diminishes when $h$ increases, but only by the factor between parentheses, for $\frac{s_0}{h}$ will be nearly constant, since it is necessary to adopt a minimum section of flange $s_0$ greater in proportion to the dimension of the girder.

For example, if the girder is $1^m \cdot 80$ high (bridge of 20 mètres), we may make $s_0$ of one plate of 3/508 millimètres and of two angle-irons of 80/80/10; for a girder of 4 mètres high ($l = 55$), we may take a plate of 550/8 with four angle-irons of 100/100/12, two of which are placed next the vertical rib and two at the edges of the flange. In both cases this would give $\frac{1 \cdot 10 R s_0}{h}$ = about 22000, and consequently U = 1·31 for $h = 1 \cdot 80$, and 1·20 for $h = 4$. We shall, therefore, vary this coefficient from 1·30 to 1·20, according as the span varies from 20 to 55 mètres.

129. The several hypotheses made in the preceding sections lead to the following Table for the weight of the lineal mètre of solid girders, the heights adopted being a little under those which would correspond rigorously with the minimum expense.

| Span .. .. .. .. .. .. .. .. | | Mètres. 20 | Mètres. 25 | Mètres. 30 | Mètres. 35 | Mètres. 40 | Mètres. 45 | Mètres. 50 | Mètres. 55 |
|---|---|---|---|---|---|---|---|---|---|
| Girders carrying one rail ($p + p' = 3600$ to 4000 kilogrammes, according to the span) .. | Height .. .. | 1·70 | 2·00 | 2·30 | 2·60 | 2·90 | 3·20 | 3·50 | 3·80 |
| | Weight a mètre | Kilos. 370 | Kilos. 485 | Kilos. 610 | Kilos. 735 | Kilos. 870 | Kilos. 1000 | Kilos. 1140 | Kilos. 1285 |
| Girders carrying one line of rails ($p + p' = 7000$ to 7400) .. .. .. | Height .. .. | Mètres. 2·25 | Mètres. 2·60 | Mètres. 2·95 | Mètres. 3·30 | Mètres. 3·65 | Mètres. 4·00 | Mètres. 4·35 | Mètres. 4·70 |
| | Weight a mètre | Kilos. 570 | Kilos. 750 | Kilos. 940 | Kilos. 1125 | Kilos. 1320 | Kilos. 1525 | Kilos. 1730 | Kilos. 1940 |

We may compute by interpolation the weight of girders supporting intermediate loads. If, for example, for a bridge of 55 mètres span we had $p + p' = 6400$ kilogrammes, we should find that by adopting a height of $4^m \cdot 45$ the weight of the lineal mètre would be about 1750 kilogrammes. This weight would be substituted for that of 1940 kilogrammes for a girder carrying one line of rails; if, instead of a load of 4000 kilogrammes, which supposes both lines loaded simultaneously, we considered a load of only about 3000 kilogrammes for the ordinary case of the passage of one train, the strain a square millimètre would then exceed 6 kilogrammes in the exceptional case of two heavily-laden trains crossing at the same time.

130. *Other Formulæ.*—In the foregoing discussions we have distinctly stated that the thickness of the vertical rib should not descend below a certain minimum, which may be fixed at $0^m \cdot 006$, but this condition has not been positively expressed in the formula; we have contented ourselves with providing for it by the aid of an approximative extra thickness. This condition is, however, easily expressed, as we shall see; but to do this we must distinguish two cases, that in which this minimum thickness of $0^m \cdot 006$ is sufficient throughout the length of the girder, and the contrary case. The vertical rib being calculated for a strain of 4 kilogrammes a square millimètre, the two case in question are equivalent to those in which the quantity $(p + p')l$ is less or greater than $48000 h$.

*First Case:* $(p + p')l < 48000 h$.—The vertical rib has a constant thickness of $0^m \cdot 006$, and it requires joint-plates with a single row of rivets on each side of the joint. We shall then have, remarking that the joint-plates are equivalent to an extra thickness of $0^m \cdot 0022$,

$$\frac{P}{l} = (p + p') \frac{l^2 t U}{6h} + h(64 + 15 \cdot 6h - 8000 t U).$$

This formula may be applied to girders carrying only one rail, provided the height be not too small. On the contrary, the formula of section 126 supposed tacitly that the height was not great, in order that the vertical rib should not become too weak. With the new expression of $\frac{P}{l}$ the most

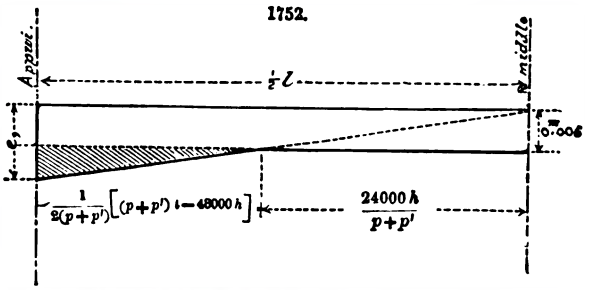
economical height will be a little less than hitherto: thus for the bridge of 20 mètres loaded with 3600 kilogrammes a mètre, it will be only $1^m \cdot 75$ instead of $1 \cdot 90$; and for the bridge of 55 mètres loaded with 4000 kilogrammes, it will be $3 \cdot 95$ instead of $4 \cdot 20$. But retaining the same heights, loads, and values of U introduced into the Table in 129, the present formula gives the following weights, which hardly differ from the preceding. This Table ends with 35 mètres span, because beyond this the condition of the present case would not be fulfilled.

| | | | | |
|---|---|---|---|---|
| Span .. .. .. .. .. .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 25 | Mètres. 30 | Mètres. 35 |
| Weight a mètre of girder carrying only one rail ($p + p' = 3600$ kilogrammes for 20 mètres span, to 3770 kilogrammes for 35 mètres) .. | Kilos. 370 | Kilos. 480 | Kilos. 600 | Kilos. 725 |

131. *Second Case:* $(p + p')\,l > 48000\,h$.—This will always be the case with girders carrying one line of rails, it will also be the case with girders carrying only one rail, if their height is below a certain value.

Fig. 1752 represents the plane of the theoretical vertical rib, throughout half the bearing, the thicknesses being exaggerated. If the plate had everywhere only $0^m \cdot 006$, its volume for the whole bearing would be $0 \cdot 006\,l\,h$; but we must add to it the triangular prisms one of which is shown in the figure. These prisms should have rigorously a curvilineal face, but we may neglect the influence of $q$, for it is perceptible only in the middle, upon the locus of the stress. The maximum stress requires at the ends a thickness $e_1 = \dfrac{(p+p')\,l}{2\,R_1\,h}$ or $\dfrac{(p+p')\,l}{8000000\,h}$ supposing $R_1 = 4000000$.

1752.




Consequently, the volume of the two additional prisms will be $\dfrac{[(p+p')\,l - 48000\,h]^2}{16000000\,(p+p')}$.

But as the thickness, instead of varying uniformly, decreases by redans or gradations of $0^m \cdot 002$, we must add a mean thickness of $0^m \cdot 001$ to the part over which the prisms extend; it may be increased to $0^m \cdot 0012$ even, to take into account various circumstances, especially that of having neglected $q$, and it will give a new supplementary volume equal to $\dfrac{0 \cdot 0012\,h}{p+p'}\,[(p+p')\,l - 48000\,h]$.

We shall have besides:—

Joint-plates and stiffening rods in the part where the vertical rib is only $0^m \cdot 006$ $\Big\} = \dfrac{48000\,h^2}{p+p'}\,(\xi_1 + \xi'_1\,h)$;

Joint-plates and stiffening rods in the part where the vertical rib is strengthened $\Big\} = \dfrac{(p+p')\,l - 48000\,h}{p+p'}\,(\xi_2 + \xi'_2\,h)\,h$.

132. Collecting the various elements of the vertical portion, as they have been computed, adding to them the flanges according to section 122, then transforming the volumes into weight, and dividing by the bearing, we shall have

$$\frac{P}{l} = \begin{cases} \dfrac{t\,U}{6\,h}\,[(p+p')\,l^2 - 0 \cdot 008\,R\,h^2] \text{ (flanges).} \\ + 46 \cdot 8\,h + \dfrac{0 \cdot 0004875}{(p+p')\,l}\,[(p+p')\,l - 48000\,h]^2 \text{ (vertical rib according to Fig. 1752).} \\ + \dfrac{9 \cdot 36\,h}{(p+p')\,l}\,[(p+p')\,l - 48000\,h] \text{ (redans in the strengthened portions of vertical rib).} \\ + \dfrac{48000\,h^2}{(p+p')\,l}\,(\xi_1 + \xi'_1\,h) + \dfrac{(p+p')\,l - 48000\,h}{(p+p')\,l}\,(\xi_2 + \xi'_2\,h)\,h \text{ (joint-plates, and so on, of the vertical rib).} \end{cases}$$

Making $R = 6000000$; $t = 0 \cdot 0013$;

Weight of the joint-plates a square mètre of vertical rib in the extreme strengthened portions .. .. $\Big\} \xi_2 = 0^m \cdot 0035 \times 7800^k = 27^k \cdot 3$,

Weight of the vertical rods a square mètre in the extreme strengthened portions .. .. .. .. $\Big\} \xi'_2\,h = 0^m \cdot 0024 \times 7800\,h = 18 \cdot 72\,h$.

Weight of the joint-plates a square mètre in the intermediate portion .. .. .. .. .. .. .. $\Big\} \xi_1 = 0^m \cdot 0022 \times 7800^k = 17^k \cdot 16$,

Weight of the vertical rods a square mètre in the intermediate portion .. .. .. .. .. .. $\Big\} \xi'_1\,h = 0^m \cdot 0016 \times 7800\,h = 12 \cdot 5\,h$;

the formula will become

$$\frac{P}{l} = (p+p')\,l\left(\frac{13\,U\,l}{60000\,h} + 0 \cdot 0004875\right) + h\,(36 \cdot 66 - 10 \cdot 4\,U + 18 \cdot 72\,h) - \frac{h^2}{(p+p')\,l}\,(298560\,h - 187200).$$

133. The most economical height will here be given by the following equation of the fourth degree (U being replaced by the expression in 64):

$$0{\cdot}0002297\,(p+p')^2\,l^3 = 25{\cdot}64\,(p+p')\,l\,h^2 + 37{\cdot}44\,[(p+p')\,l + 10000]\,h^3 - 895680\,h^4,$$

which ought to give values a little greater than hitherto, since we have expressed the fact that, in proportion as the height increases, the lengths of the portions of vertical rib which need to be strengthened are reduced. And, in fact, for $l = 20$ mètres, and $p + p' = 7000$ kilogrammes, we obtain $2^m{\cdot}70$, instead of $2^m{\cdot}45$, found by the first formula; and for $l = 55$, and $p + p' = 7400$, we find $5{\cdot}45$, instead of $5{\cdot}20$.

By increasing the heights, therefore, a little, we shall form by means of the last formula the following Table, in which $p + p'$ varies from 7000 to 7400, and U from 1·30 to 1·20, in proportion as the bearing increases from 20 to 55 mètres. These loads refer to girders carrying two rails, a test which in general is realized in a complete manner only when both lines are simultaneously loaded.

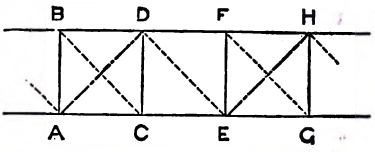
| | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. |
|---|---|---|---|---|---|---|---|---|
| Span .. .. .. .. .. .. .. | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Height .. .. .. .. .. .. .. | 2·50 | 2·85 | 3·20 | 3·55 | 3·90 | 4·25 | 4·60 | 5·00 |
| | Kilos. | Kilos. | Kilos. | Kilos. | Kilos. | Kilos. | Kilos. | Kilos |
| Weight of the mètre of girder .. .. | 535 | 710 | 890 | 1070 | 1265 | 1460 | 1670 | 1870 |

These weights are a little less than those obtained by the first method.

134. *Example of Solid Girder*, Figs. 1753 to 1757: $l = 35$ mètres, $p + p' = 7000$ kilogrammes.—According to a direct calculation, this girder weighs only 1030 kilogrammes a lineal mètre. The arrangements shown in the plan for the joint-plates of the flanges allows us to reduce the coefficient U to the value 1·20.

135. *Girders with Inclined Stays.*—When vertical stays or rods are not deemed necessary for the purpose of affixing cross-girders or brackets, they may be replaced by oblique pieces crossing the flat joint-plates, which would remain vertical and would be interrupted in the line of these pieces. The latter would be inclined to 45°, nearly normally to the wrinkles which would be produced if the plate were not stiffened. This arrangement is alluring, however, the economical advantage of it appears doubtful, because for the same normal distance between the consecutive pieces the diminution of their number would be compensated by the increase in their length; or rather the distance between the oblique bars may be greater, but their section should be increased to an equal degree, for these pieces, concentrating upon themselves by the effect of their rigidity the strains of compression, may be considered as the struts of a lattice which would be completed by the tension of the plate in the direction of one of the diagonals of each panel. Now for one direction given to these diagonal tensions of the plate, we may replace two vertical stays A B, C D, Fig. 1758, by a single stay A D, which would be equivalent to them, for with the inclination of 45°, for example, it would have its strain and its length multiplied by $\sqrt{2}$. Thus between the imaginary lattice A B C D E F G, and the lattice A D E H, there would be this essential difference only, namely, that in the second, the plate will be relieved of the diagonal tensions B C, F G, in the rectangular panels occupied by the oblique bars. But there is small advantage in this, since this plate must resist equal strains in other panels, and besides, these stays were not intended to reduce these strains.

1758.

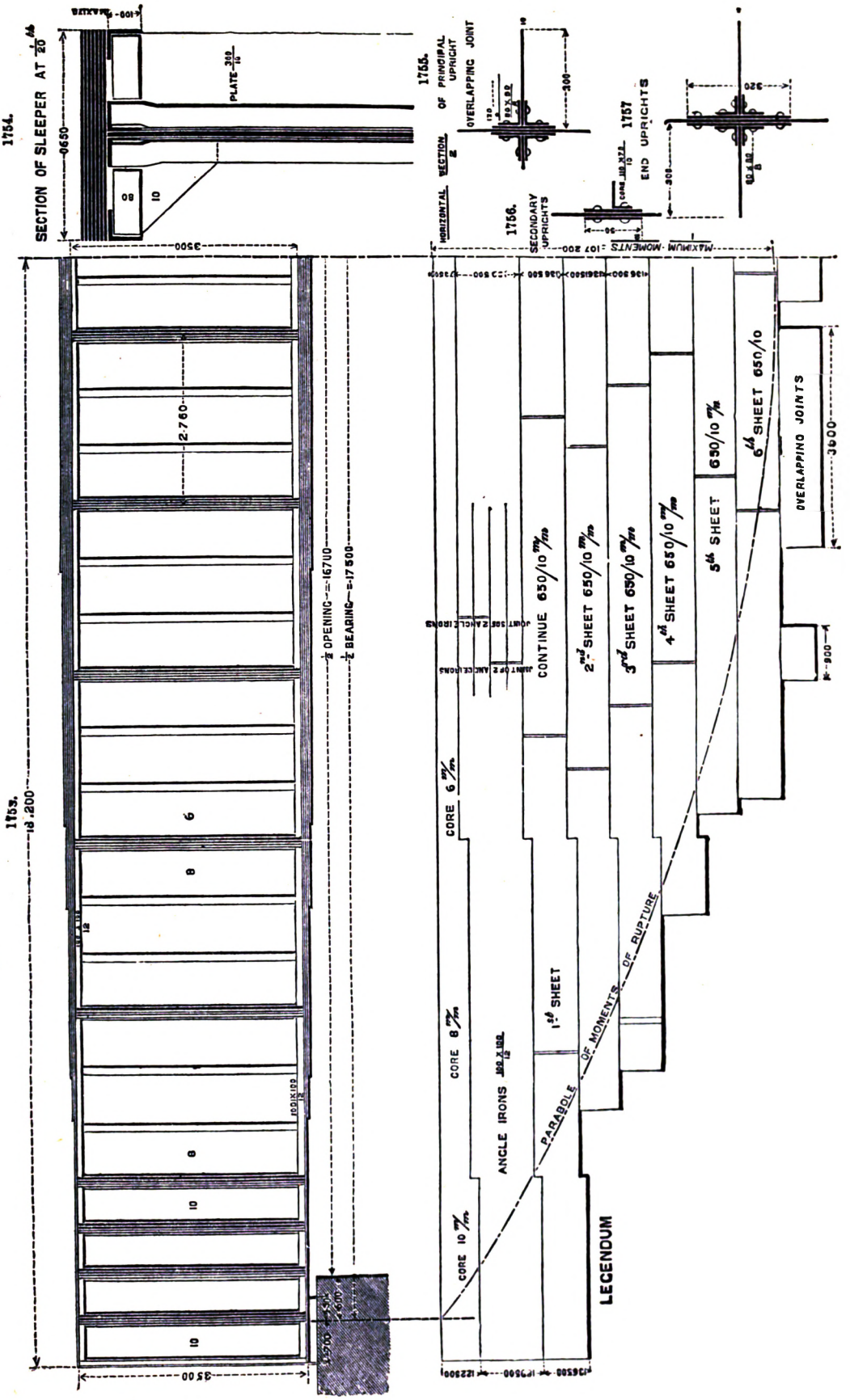



The adoption of oblique pieces will in no degree change the form of the formulæ of weight given, 119 to 135. It would be sufficient to introduce other values for the weight of the stays a square mètre of vertical rib, if it were thought a reduction might be made.

136. *Formulæ applicable to Bow Bridges.*—Bow-girders are metallic frames consisting of two curved flanges more or less distant from each other in the middle, and approaching each other towards the extremities where they are bound together by strong wrought-iron plates. If we consider any vertical section, the action of the flanges, having an inclined direction, will produce a vertical force capable of resisting, in part at least, the stress upon the bridge. The lattice connecting the flanges at certain intervals may thus be greatly relieved.

If the lattice is a simple one, the bars, or at least some of them, must necessarily possess sufficient rigidity to resist compression. This is doubtless a great disadvantage, for the theoretical strains being small we shall obtain the rigidity only at the cost of a great increase of section. This increase, however, is confined within rather narrow limits, even if we do not bring into play the rigidity of the bow itself since the coefficient of stiffness, if it has a high value, is applied to only a small fraction of the total weight. We may, therefore, not hesitate to adopt for this coefficient a value of 2·50, for instance, which raises to 60 the ratio of the length to the reduced thickness (68). But, by doubling the diagonals of the lattice, we may in certain cases entirely suppress the compressions in the vertical portion, or at least render them unworthy of consideration, as we shall see in 144 and 157. As an expenditure of material, this will amount to nearly doubling the theoretical weight of simple diagonals not possessing rigidity; for we arrive at this elimination of the compressions only by supposing, in any cross, that one of the diagonals of which it is composed remains inactive at a given moment. The compression is always thrown upon the vertical rods, where it is destroyed or very much reduced by a permanent tension due to the dead weight of the flooring.

These considerations allow us to study bow bridges as simple articulate systems, which will lead us to formulæ for the computation of their weight more precise and simple than the method

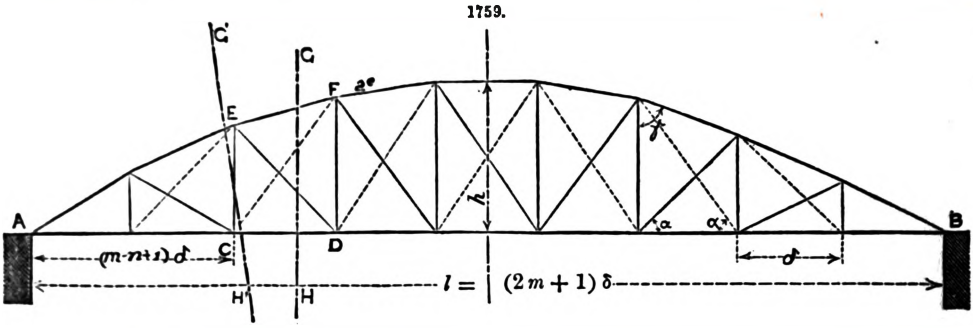

1754.
SECTION OF SLEEPER AT 1/20th
PLATE 300/10
1755.
OF PRINCIPAL UPRIGHT
OVERLAPPING JOINT
HORIZONTAL SECTION
1756.
SECONDARY UPRIGHTS
1757
END UPRIGHTS
MAXIMUM MOMENTS
1753.
18.200
2.760
3500
½ OPENING = 16700
½ BEARING = 17500
CORE 6 m/m
CORE 8 m/m
CORE 10 m/m
ANGLE IRONS 100 X 100/12
1st SHEET
CONTINUE 650/10 m/m
2nd SHEET 650/10 m/m
3rd SHEET 650/10 m/m
4th SHEET 650/10 m/m
5th SHEET 650/10 m/m
6th SHEET 650/10
OVERLAPPING JOINTS
PARABOLE OF MOMENTS OF RUPTURE
LEGENDUM

of introducing the rigidity of the bows themselves, and, consequently, the form of their section, could do. When a scheme is devised in which this rigidity plays an important part, it is because something is to be gained by it, and then our computations will still be useful if we consider them as forced a little.

It is generally more convenient to make only the upper flange or bow arched, the lower flange or stringer being straight and provided with points for fixing the cross-girders. We shall designate more specially this particular form by the name of *arched girder*.

137. *Parabolical Arched Girder, divided into an odd number of intervals*, Fig. 1759.—Let $l = (2m+1)\delta$ be the bearing and $h$ the height in the middle. The bars, whether vertical or oblique, are num-

1759.




bered from the middle. The bow is a polygon, having its summits upon a parabola with a vertical axis, and the sides of which have a constant horizontal projection equal to $\delta$.

The $n$th vertical rod has a length expressed by $h\left[1 - \frac{n(n-1)}{m(m+1)}\right]$, and the value of the sum of the lengths of the $2m$ rods is $\frac{2h}{3}(2m+1)$ or $\frac{2}{3}\frac{lh}{\delta}$. The length of the $n$th section E F of the curved flange is $\frac{1}{m(m+1)}\sqrt{m^2(m+1)^2\delta^2 + 4(n-1)^2h^2}$, and makes with the vertical an angle $\gamma$ given by cotan. $\gamma = \frac{2h(n-1)}{m(m+1)\delta}$.

The length of the $n$th diagonal shown by the full line is

$$\frac{1}{m(m+1)}\sqrt{m^2(m+1)^2\delta^2 + [m(m+1) - n(n-1)]^2h^2},$$

and makes with the horizon an angle $\alpha$ the sine of which is

$$\text{Sin. } \alpha = \frac{m(m+1) - n(n-1)}{\sqrt{m^2(m+1)^2\delta^2 + [m(m+1) - n(n-1)]^2h^2}}.$$

The length of the $n$th diagonal shown by the dotted line is

$$\frac{1}{m(m+1)}\sqrt{m^2(m+1)^2\delta^2 + [m(m+1) - n(n-1)(n-2)]^2h^2},$$

and the sine of the angle of inclination is

$$\text{Sin. } \alpha' = \frac{m(m+1) - (n-1)(n-2)}{\sqrt{m^2(m+1)^2\delta^2 + [m(m+1) - (n-1)(n-2)]^2h^2}}.$$

138. 1.—Let us first suppose a simple lattice formed by the vertical rods and the diagonals shown by the full lines.

If the framing is subjected only to a permanent load uniformly distributed according to the horizontal, in such a manner that a weight equal to $p\delta$ is applied to the foot of each vertical rod, this weight will express the constant tension of all the rods, which act as simple suspension-rods to transmit the load to the several summits of the polygonal arc. Their total theoretical weight will be $= \frac{2}{3}(2m+1)p\delta ht$, $t$ denoting as before the ratio of the weight of the cubic mètre of iron to the admitted resistance R.

The $n$th section of the bow is subject to the following strain of compression:

$$\frac{p\delta}{2h}\sqrt{m^2(m+1)^2\delta^2 + 4(n-1)^2h^2};$$

whence we deduce for the total weight of the bow the value $\text{U}(2m+1)p\delta t\left[\frac{m(m+1)\delta^2}{2h} + \frac{2h}{3}\right]$.

The lower flange, or stringer, bears a constant tension equal to $\frac{m(m+1)p\delta^2}{2h}$, which gives it a total weight $= \frac{\text{U}m(m+1)(2m+1)p\delta^3t}{2h}$. The letter U still denoting the coefficient for joint-plates and other accessories.

It is useless to enlarge upon these formulæ, well known in the theory of suspension bridges.

With the present mode of loading, the parabolic form given to the bow assimilates it to a funicular polygon, that is, its several elements have precisely the directions which they would of themselves assume if they were left free to turn about their summits. It is, indeed, easy to prove that the action of any section has a vertical projection equal to the stress, so that the diagonal is inactive.

139. It will not be the same in the case of a moving load which, although distributed uniformly in the proportion of $p'\,\delta$ a vertical rod, may exist on a certain portion only of the length.

To find the maximum strains upon the several sections of the flanges, the load must be extended over the whole bridge; for these strains depend only upon the moments of rupture about certain summits, and these moments increase always in proportion as we add new loads upon a certain point in the bearing. The strains and weight of the flanges will, therefore, be obtained by the formulæ of the preceding section by substituting $p + p'$ for $p$.

But the strains upon the bars are at once functions of the moment of rupture and the stress.

Let T be the strain upon the diagonal E D, Fig. 1759, M the moment of rupture about the point D, the abscissa of which is $(m - n + 2)\,\delta$, and F the stress between C and D. The strain upon the section E I of the bow will be equal to $\frac{M}{D\,I \sin.\,\gamma}$, and, consequently, considering the portion of the girder situate to the left of the line G H, the condition of equilibrium relative to the vertical forces will give, supposing T to be a tension, $T = \frac{F}{\sin.\,\alpha} - \frac{M \cot.\,\gamma}{D\,I \sin.\,\alpha}$.

This expression is of the form $B\,F - A\,M$, A and B being given quantities. Therefore, from section 7, it will become a maximum when the load is applied to the point D and to all those on the right. Taking this maximum value, and substituting the values of cotan. $\gamma$, sin. $\alpha$ and D I (the length of the $(n-1)$th vertical rod), we find that the diagonal should be capable of resisting a strain of tension,

$$T = \frac{p'\,\delta}{2\,(2m+1)\,h}\sqrt{m^2\,(m+1)^2\,\delta^2 + [m\,(m+1) - n\,(n-1)]^2\,h^2}.$$

We know that if we complete the load by adding weights $p'\,\delta$ at the bottom of the vertical rods situate to the left of G H, the diagonal will be relieved of its strain. Therefore, this complementary load placed alone in its turn should produce a compression equal to the preceding tension. Thus, applying a coefficient of stiffness V, the weight of the diagonal in question will be

$$\frac{p'\,\delta\,t\,V}{2m\,(m+1)\,(2m+1)}\left\{m^2\,(m+1)^2\,\frac{\delta^2}{h} + [m\,(m+1) - n\,(n-1)]^2\,h\right\}$$

To find the total weight of the $2m-1$ diagonal bars, we must scan the preceding expression in which $n$ takes the successive values $1, 2, \ldots m$, double the result, and then subtract what the above expression becomes for $n = 1$, in order not to reckon twice the middle diagonal. We shall be induced, for the sake of symmetry, to divide this diagonal into two pieces to form a central cross, but the strain will be distributed between the two bars of this cross, and there will be no increase of weight. We obtain:

Total weight of the $(2m-1)$ diagonals shown by the full lines,

$$\frac{p'\,\delta\,t\,V}{2\,(2m+1)}\left[m\,(m+1)\,(2m-1)\,\frac{\delta^2}{h} + \frac{h}{15}\,(16\,m^3 + 9\,m^2 + m + 4)\right].$$

140. Analogous calculations may be applied to the $n$th vertical rod C E. Cutting it by a section G′ H′, supposing it to be subject to a compression T′, and calling M′ the moment of rupture about a point C, the abscissa of which is $(m - n + 1)\,\delta$, we shall have by the equation of equilibrium relative to the projections of the vertical forces, $T' = F - \frac{M' \cot.\,\gamma'}{E\,C}$; $\gamma'$ is the angle of the $(n+1)$th section of the bow with the vertical, and E C the length of the $n$th rod.

This expression is also of the form $B\,F - A\,M'$. Treating it by the rule in section 7, we obtain for the maxima compression of the rod, $T' = \frac{(m-n)\,(m+n-1)}{2\,(2m+1)}\,p'\,\delta$.

Here F was the stress taken beyond the point to which the moment M′ is referred. It follows that this maximum strain T′ is produced when the load is applied to the point D, and to those following it as far as B. This compression will be wholly or partly neutralized by the permanent tension due to the dead weight.

When the load is completed, the vertical rod, instead of being subject to a strain of compression T′, is, on the contrary, subject to a strain of tension $p'\,\delta$. Therefore the complementary load placed alone in its turn should subject the rod to a tension

$$T'' = p'\,\delta + T' = \frac{(m+n+1)\,(m-n+2)}{2\,(2m+1)}\,p'\,\delta,$$

which always greatly exceeds the maxima compression, especially when we add the permanent tension $p\,\delta$, due to the dead weight.

It may happen that this latter tension is always sufficient to destroy the compressions which the load may produce. We may, therefore, from this point of view dispense with a coefficient of stiffness, and calculate the rods by tension only. Adding the dead to the moving load, and denoting the ratio $\frac{p}{p+p'}$ by $q$, the weight of the $n$th rod will be

$$(p+p')\,\delta\,t\,h\left[1 - \frac{n\,(n-1)}{m\,(m+1)}\right]\left[1 + q\,\frac{(m+n-1)\,(m-n)}{2\,(2m+1)}\right],$$

an expression which being doubled, then summed from $n = 1$ to $n = m$ inclusive, leads to

Total weight of the $2m$ vertical rods $= \frac{2(p+p')\delta t h}{3}\left[2m+1+q\,.\,\frac{(m-1)(2m-1)}{5}\right]$.

141. Adding the weight of the flanges, of the diagonals and of the vertical rods, substituting for $\delta$ its value in $l$, and dividing by $l$, we obtain for the mean weight of the lineal mètre of girder,

$$\frac{P}{l} = (p+p')\,t l^2\,\frac{m(m+1)}{(2m+1)^2}\left[U + qV\,\frac{2m-1}{2(2m+1)^2}\right]\frac{1}{h} + \frac{(p+p')\,th}{3}$$

$$\left\{2(U+1) + \frac{q}{10(2m+1)^2}\left[16m^3(1+V) - m^2(16-9V) - m(4-V) + 4(1+V)\right]\right\} + \Omega.$$

The term $\Omega$ includes accessories independent of $h$.

Substituting N for $2m+1$, we may write also

$$\frac{P}{l} = (p+p')\,t l^2\,.\,\frac{N^2-1}{4N^2}\left(U + qV\,.\,\frac{N-2}{2N^2}\right)\frac{1}{h} + \frac{(p+p')\,th}{3}$$

$$\left\{2(U+1) + \frac{q}{40N^2}\left[8N^3(1+V) - 5N^2(8+3V) + 8N(6+V) + 15V\right]\right\} + \Omega.$$

Such is the formula applicable, N being odd, to a bow-girder with simple rigid diagonals. If the height is great, the vertical rods may with advantage possess rigidity, because they may furnish resting points for fixing the vertical cross-bracing which is needed to maintain the verticality of the girder. In such cases we may either subject them to a coefficient V, or retain the preceding formula, by adding to it a term $\frac{2}{3}\frac{N\theta h^2}{l}$ for the addition, to each rod, above the theoretical section, of a projecting rib weighing $\theta h$ a lineal mètre.

The first method would have the advantage of simplifying the formula by reducing it to

$$\frac{P}{l} = (p+p')\,t\left\{\frac{N^2-1}{4N^2}\,.\,\frac{l^2}{h}\left(U + qV.\frac{N-2}{2N^2}\right) + \frac{h}{3}\left[2(U+1) + \frac{qV}{40N^2}(16N^3 - 55N^2 + 56N + 15)\right]\right\} + \Omega.$$

142. 2.—If the diagonals shown by the full lines of Fig. 1759 are now suppressed and replaced by the diagonals shown by the dotted lines, we shall have another system of simple lattice, which will give occasion to analogous calculations. The value of the strain either by tension or by compression upon the $n$th diagonal is

$$\frac{p'\delta}{2(2m+1)h}\sqrt{m^2(m+1)^2\delta^2 + [m(m+1) - (n-1)(n-2)]^2 h^2},$$

and consequently we have:

Total weight of the $2m-1$ diagonals shown by the dotted lines $=$

$$\frac{p'\delta t V}{2(2m+1)}\left\{\frac{m(m+1)(2m-1)\delta^2}{h} + \frac{h}{15(m+1)}(16m^4 + 55m^3 + 70m^2 - 85m + 4)\right\}.$$

The vertical rods are subject to the same strains, and make up the same total weight as with the first system of diagonals.

143. 3.—Generally a single system of diagonals will not be sufficient, and a girder of complete crosses will be adopted. The strains are then indeterminate, and we are free to calculate the pieces from one or the other of the two following points of view.

We may, in the first place, consider the complex system as resulting from the superposition of two simple lattices, each comprising a certain portion of the section of the flanges and vertical rods, plus one of the systems of diagonals, to the exclusion of the other. It is natural to attribute a half of the load to each of these two constituent parts; and, consequently, the diagonals will have their strains and their weights given by the same formulæ as if they were simple, by changing $p'$ into $\frac{1}{2}p'$. The flanges retain the same weight; as to the vertical rods, the present hypothesis divides them into two portions, one of which is subject to a strain of compression and the other to a strain of tension, under the action of a determinate load extending over a part only of the flooring. For example, if the load be applied only to the rod under consideration and to all those to the right, it will produce upon this rod on the one hand a tension $\frac{p'\delta}{4(2m+1)}(m^2 + 3m - n^2 + n + 2)$, and on the other hand a compression $\frac{p'\delta}{4(2m+1)}(m^2 - n^2 - 3m - n - 2)$. The resultant is a tension $\frac{3m+n+2}{2(2m+1)}p'\delta$, the maximum of which is $p'\delta$ for $n = m$. Now this maximum is required of all the vertical rods when the bridge is completely loaded. They must, therefore, be all calculated for a tension equal to $(p+p')\delta$, without taking into account their mode of participating in the resistance of the two component simple lattices.

We therefore give:

Total weight of the $2m$ vertical rods $= \frac{2}{3}(2m+1)(p+p')\delta t h$.

The total weight of the mètre of girder is then

$$\frac{P}{l} = \frac{(p+p')t}{(2m+1)^2}\left\{m(m+1)l^2\left(U + \frac{qV}{2(2m+1)}\right)\frac{1}{h} + \frac{2}{3}\left[(U+1)(2m+1)^2 + qV\,.\,\frac{4m^4 + 10m^3 + 10m^2 - 10m + 1}{5(m+1)}\right]h\right\} + \Omega,$$

or, if $l$ is expressed by $N\delta$ (N being odd),

$$\frac{P}{l} = (p+p')t\left\{\frac{N^2-1}{4N^2}l^2\left(U+\frac{qV}{2N}\right)\frac{1}{h}\frac{2h}{3}\left[U+1+\frac{qV}{10}\left(N+\frac{1}{N}-\frac{30(N-1)}{N^2(N+1)}\right)\right]\right\}+\Omega;$$

a formula to which we shall generally have to add (141) a term $\frac{2}{3l}N\theta h^2$, allowing us to enlarge the vertical rods by means of projecting ribs or gussets for the purpose of maintaining the verticality of the girder.

144. But the diagonals being very long and subject to small strains, can be stiffened only by means of a high value of V. Now, considering them as very flexible rods, unable to resist any compression, they will of themselves elude this kind of strain by yielding, and the lattice will assume another mode of resistance, in virtue of which the strains of compression will always be thrown upon the vertical rods. Choosing diagonals which at any instant are prepared for a tensile strain, the whole framing will offer a constant resistance. From this point of view, the two systems of diagonals will be calculated each for the whole load, which is equivalent to making V = 2, in the formula of the preceding section. It is true that in this case the vertical rods may be required to resist compression, but it will be to a very small coefficient, for the permanent tension $p\delta$ neutralizes in a great measure, if not altogether, the strains in the opposite direction. The real strain of compression, if such be produced, is limited to $\frac{p'\delta}{2(2m+1)}(m-n)(m+n-1)-p\delta$, whilst under a complete load the maximum tension reaches $(p+p')\delta$. If, therefore, $p$ be not less than $\frac{m(m-1)}{2(2m+1)}p'$ the vertical rods can never be subject to compression, in which case we obtain this remarkable result, that all the lattice-bars have to resist tensile strains only, which obviates the necessity for rigidity. This allows us to adopt great heights for girders, and to make the arched form more advantageous than the straight. These favourable conditions still exist when the maxima compression of the vertical rods, without being always nul, remains at least within certain limits; and if there is occasion for applying to these rods a coefficient V, as we are about to do, it is much less on account of the possible compression, than for the purpose of maintaining the vertical position of the girder by means of suitable arrangements; such, for instance, as the vertical cross-bracing fixed to the rods in Fig. 1762, which rods must furnish sufficiently firm points. By adding this coefficient V applied to the vertical rods (but no longer affecting the diagonal bars), the addition of a term $\frac{2}{3}\frac{N\theta h^2}{l}$ as in the preceding case, is rendered superfluous. It is the same addition expressed under another form.

It is evident that there will be an advantage in bringing the pieces of the vertical portion of the girder into accordance with the second hypothesis rather than with the first, whenever the latter would require for the rigidity of the diagonals the application of a coefficient V greater than 2. But it is scarcely necessary to remark that, although freed from all compression according to the second hypothesis, the diagonals will offer greater security if we give them all the rigidity which, with a convenient form, the area of their theoretical section admits, for we shall thus render them capable of resisting at pleasure in two different ways; the mode of effective resistance will be a kind of mean which will limit the real strains to a figure smaller than the admitted limits.

145. From the considerations in the preceding section, the weight of the lineal mètre of arched girder with complete crosses may be represented by

$$\frac{P}{l} = \frac{(p+p')t}{(2m+1)^2}\left\{m(m+1)l^2\left(U+\frac{q}{2m+1}\right)\frac{1}{h}+\frac{2h}{3}\right.$$
$$\left.\left[(U+V)(2m+1)^2+\frac{2q}{5(m+1)}(4m^4+10m^3+10m^2-10m+1)\right]\right\}+\Omega;$$

or, if $l$ is expressed by $N\delta$ (N being odd),

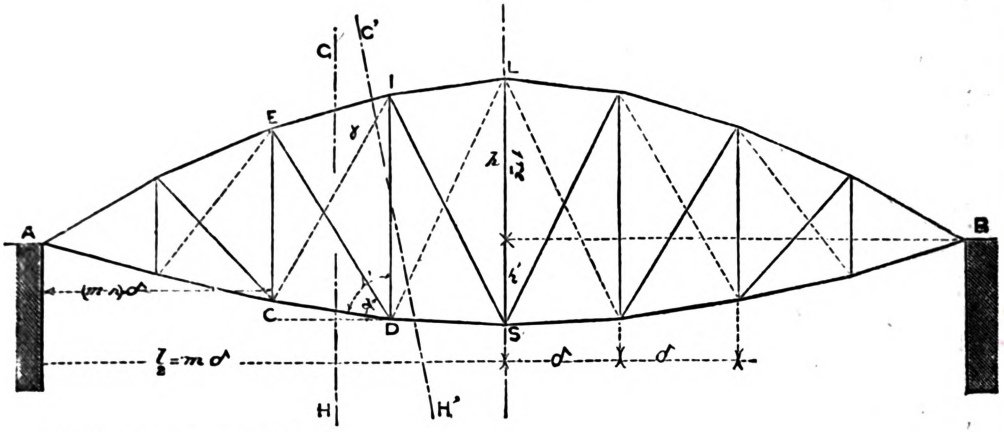
$$\frac{P}{l} = (p+p')t\left\{\frac{N^2-1}{4N^2}l^2\left(U+\frac{q}{N}\right)\frac{1}{h}+\frac{2h}{3}\left[U+V+\frac{q}{5}\left(N+\frac{1}{N}-\frac{30N-1}{N^2(N+1)}\right)\right]\right\}+\Omega.$$

146. *Parabolic Bow-girder divided into an even number of intervals.*—We will now suppose that the bearing $l$ is expressed by $2m\delta$, and we shall consider the general case of a bow both flanges of which are curved, as in Fig. 1760.

The total height in the middle is the sum of the versed sines $h$ and $h'$ of the curve above and below the horizontal A B, drawn through the points of meeting at the ends. The various pieces are, as before, numbered from the middle.

If the flooring were placed according to the tangent to the lower flange, we should have to lengthen the vertical rods to this tangent and to add a horizontal longitudinal girder. But nothing prevents us from placing the flooring at the height of the line A B, and saving, if not the longitudinal girder, at least the lengthening of the vertical rods; unless the upper bow be, as in the bridge at Saltash, formed of a single tubular section projecting over the space occupied by the flooring, an arrangement which requires the extremities A and B to be kept at a sufficient height above the rails. But two distinct framings well tied and braced together, leaving, of course, a free passage for the trains, may constitute a sufficiently rigid whole; and we shall, consequently, consider only the pieces represented in the figure, except the casual addition of a longitudinal beam tying together the vertical rods at the height of the flooring, this piece being regarded as included in the term $\Omega$ independent of the height.

1760.




We have as geometrical data:

Length of the $n$th vertical rod $= \frac{m^2-(n-1)^2}{m^2}(h+h')$;

Sum of the lengths of the $2m-1$ vertical rods $= (h+h')\frac{(4m^2-1)}{3m}$;

Length of the $n$th section of upper flange $= \frac{1}{m^2}\sqrt{m^4\delta^2+(2n-1)^2h^2}$;

Length of the $n$th diagonal shown by a full line $= \frac{1}{m^2}\sqrt{m^4\delta^2+[(m^2-n^2)(h+h')+(2n-1)h']^2}$.

This diagonal is inclined upon the horizon at an angle $\alpha$ given by

$$\text{Sin. } \alpha = \frac{(m^2-n^2)(h+h')+(2n-1)h'}{\sqrt{m^4\delta^2+[(m^2-n^2)(h+h')+(2n-1)h']^2}}.$$

The $n$th section of upper flange makes with the vertical an angle $\gamma$ such that $\text{cotan. } \gamma = \frac{(2n-1)h}{m^2\delta}$.

We shall obtain the analogous quantities, relative to the lower flange and to the diagonals shown by the dotted lines, by simply changing $h$ into $h'$, and $h'$ into $h$.

147. The flanges should always be calculated under a full load, whatever the diagonals adopted may be. The value of the strain upon the $n$th section of the upper flange is

$$\frac{(p+p')\delta}{2(h+h')}\sqrt{m^4\delta^2+(2n-1)^2h^2},$$

and that upon the $n$th lower section is found by the same formula modified by interchanging $h$ and $h'$, which only alters the second term under the radical. If we cut these two corresponding sections according to the radical, their action will furnish a vertical resultant projection equal to $\frac{(p+p')\delta}{2}(2n-1)$, which is exactly in equilibrio with the stress; thus, when the load is complete throughout the length of the bridge, the diagonals do not resist.

The weight of the $n$th section of the upper flange being expressed by

$$\frac{(p+p')\delta t}{2m^2(h+h')}[m^4\delta^2+(2n-1)^2h^2],$$

we conclude that the total weight of this flange will be $\frac{(p+p')\delta t}{h+h'}\left[m^3\delta^2+(4m^2-1)\frac{h^2}{3m}\right]$, and adding the coefficient U, the two flanges together will weigh

$$\frac{(p+p')\delta t\,U}{h+h'}\left[2m^3\delta^2+(4m^2-1)\frac{(h^2+h'^2)}{3m}\right].$$

148. The load still extending over the whole bearing, the strain upon the vertical rods will be found by remarking that, for the equilibrium of the point I, the rod D I must destroy the resultant of the strains from the two sections L I and E I, abutting at this point, the diagonals being inactive, as we have just seen. We have:

Tension of the $n$th rod $= (p+p')\delta\frac{h}{h+h'}$, a constant value whatever $n$ may be.

In the case in which the maximum strain is always limited to this value, the total weight of the $2m-1$ rods will be independent of $h'$, and will have as its expression $(p+p')\delta t h\frac{4m^2-1}{3m}$.

This supposes that the load is applied to the bottom of the vertical rods. If, on the contrary, the flooring is on a level with the line A B, the upper portion of each rod will have the same

tensile strain as before, but the lower portion will bear a compression $(p + p')\,\delta\,\frac{h'}{h + h'}$, and if we give different sections to the two portions, the total weight will be expressed by

$$(p + p')\,\delta\,t \cdot \frac{4\,m^2 - 1}{3\,m} \cdot \frac{h^2 + \mathrm{V}\,h'^2}{h + h'},$$

V being a coefficient of stiffness applied to the compressed portions, and which may be extended to the upper portions for the purpose of adding rigidity to the bridge considered as a whole.

149. If the diagonals shown by the full lines alone existed, we should find the strain T upon the $n$th diagonal E D, Fig. 1760, by cutting it by a plane G H, and expressing the nullity of the sum of the vertical projections of the forces applied to the portion of the framing comprised between A and the section G H.

But the $n$th section of the upper flange, cut by the line G H, is subject to a strain of compression $= \frac{\mathrm{M}}{\mathrm{I\,D} \times \sin.\,\gamma}$, M being the moment of rupture about the point D. The section C D is subject, on the contrary, to a tensile strain $= \frac{\mathrm{M'}}{\mathrm{E\,C} \times \sin.\,\gamma'}$, M' being the moment of rupture at the point E or C. Consequently, if F = the stress in the interval C D, we shall have

$$\mathrm{T} \sin.\,\alpha = \mathrm{F} - \frac{\mathrm{M}\,\mathrm{cotan.}\,\gamma}{\mathrm{I\,D}} - \frac{\mathrm{M'}\,\mathrm{cotan.}\,\gamma'}{\mathrm{E\,C}}$$

This expression being of the form $\mathrm{F} - \mathrm{A\,M} - \mathrm{A'\,M'}$, will be a maximum when the load goes from D (inclusive) to the abutment B, according to the observation made in section 7. Applying the general rule, and replacing cotan. $\gamma$, cotan. $\gamma'$, and the lengths I D, E C, of the $n$th and $(n + 1)$th vertical rods by their values, we arrive at the maximum tensile strain upon the diagonal, namely, $\mathrm{T} = \frac{p'\,\delta}{4\,m\,(h + h')} \sqrt{m^4\,\delta^2 + [(m^2 - n^2)\,(h + h') + (2\,n - 1)\,h']^2}$. The weight of this bar is

$$= \frac{p'\,\delta\,t}{4\,m^3\,(h + h')} \{\, m^4\,\delta^2 + [(m^2 - n^2)\,(h + h') + (2\,n - 1)\,h']^2 \,\}.$$

Summing this expression, in which $n$ takes the successive values $1, 2, \ldots m - 1$, then doubling that the result may include the whole bearing, we obtain as the total weight of the $2\,(m - 1)$ diagonals in full lines,

$$\frac{p'\,\delta\,t}{60\,m^2\,(h + h')} \Big\{ 30\,m^3\,(m - 1)\,\delta^2 + (16\,m^4 - 15\,m^3 - 1)\,h^2$$

$$+ \left(16\,m^4 + 15\,m^3 - 120\,m + 119 - \frac{30}{m}\right) h'^2 + 8\,(4\,m^4 - 5\,m^2 + 1)\,h\,h' \Big\}.$$

In a simple lattice, we must multiply this weight by a coefficient of stiffness; for the bars are subject, under a partial complementary load, to compressions as great as the tensions T.

A load extending from one abutment to any point in the flooring, causes a strain of compression upon all the diagonals (full lines) in the half-bay contiguous to this abutment, and one of tension upon all those of the opposite half-bay.

150. Having still only the diagonals shown by the full lines, a partial load upon the right side will cause upon the $n$th vertical rod a strain of compression, the value of which will be found by considering a section such as G' H', Fig. 1760, and writing again the equation of the vertical projections of the forces. Into this equation will enter the stress after the point D, and the moment of rupture about this point, a moment upon which depend the strains upon the divisions E I, D S, crossed by the section G H. We shall find as the maximum of the compression sought, due to the load $p'$, $\frac{p'\,\delta\,(m + n - 2)}{4\,m\,(h + h')} [(m - n)\,(h + h') + 2\,h']$, a formula which does not apply to the middle bar, for which $n = 1$.

The effective compression which may be produced will be only the difference between the above value and that of the permanent tension $\frac{p\,\delta\,h}{h + h'}$.

The maxima tension will exceed the compression by the whole value $\frac{(p + p')\,\delta\,h}{h + h'}$; for the special effect of a partial load upon the left side, complementary of the preceding, should be to annul, in the first place, the compression produced by the load on the right, and then besides this to raise the tension to the value which it possesses when the weights $p'\,\delta$ are applied to all the vertical rods. Thus this complementary load, acting above, will produce, adding the permanent strain, a tension $\frac{(p + p')\,\delta}{h + h'} \left\{ h + q\,\frac{(m + n - 2)}{4\,m} [(m - n)\,(h + h') + 2\,h'] \right\}$, according to which the weight of the vertical rods should be calculated, if the diagonals shown by the full lines exist alone, and the load be applied to the bottom of the rods.

151. But if the load be placed at the height of the line A B, passing through the points of junction of the flanges, the lower portion of the vertical rod will be subject to less tension and to greater compression, for the stress will not be the same when the line G' H' cuts the rod above or below the points where the flooring is affixed. When the weights $p'\,\delta$ are applied only to the $n$th vertical rods and to all those on the right, the lower portion of this $n$th rod will be subject to a strain of compression $= p'\,\delta\,\frac{m + n}{4\,m} \cdot \frac{(m - n)\,(h + h') + 2\,h'}{h + h'} + \frac{p\,\delta\,h'}{h + h'}$.

152. The middle vertical bar is an exception to the preceding formulæ, because a secant plane cannot cross it without cutting a diagonal also. But the strain upon this rod is determined by the condition of being in equilibrio with the resultant, always vertical, of the compressions borne by the two sections of the upper flange. When the bridge is completely loaded, the rod supports a maxima tension of $\frac{(p+p')\,\delta\,h}{h+h'}$ in its upper portion; and below the point where it receives the cross-girder, it is at the same time subject to a strain of compression of $\frac{(p+p')\,\delta\,h'}{h+h'}$; but the compression will be greater if we unload the bridge entirely, with the exception of the middle rod under consideration, and in this case it reaches the value $\frac{(p+p')\,\delta\,h'}{h+h'}+p'\,\delta\,\frac{(m-1)\,h}{m\,(h+h')}$ or $\frac{(p+p')\,\delta\,h'}{h+h'}\left[1+\frac{(m-1)\,h}{m\,h}\,q\right]$. If, on the contrary, the load were over the whole of the bridge, except upon the middle rod, the lower portion of this rod would support only $\frac{p\,\delta\,h'}{h+h'}-\frac{p'(m-1)\,\delta\,h}{m(h+h')}$ which may be changed into tension if the sign becomes negative.

153. If now we exclude the diagonals shown by the full lines and adopt those shown by the dotted ones, it is easy to see that we shall obtain the strains and the weights of the latter by the formulæ found for the former in 149, by merely changing $h$ into $h'$ and $h'$ into $h$, as if the girder were turned upside down.

As to the vertical rods, the $n$th one will bear, at least in its upper portion, a maxima tension $=\frac{p\,\delta\,h}{h+h'}+p'\,\delta\,\frac{(m+n)\,(m-n)\,(h+h')+2\,h}{4\,m\,(h+h')}$; and if the load be applied to a certain point in the height of the rod, the portion below this point may be compressed by a force equal to $p'\,\delta\,\frac{m-n+2}{4\,m}\cdot\frac{(m+n)\,(h+h')-2\,h}{h+h'}+\frac{p\,\delta\,h'}{h+h'}$, which will be produced when the rod in question and those on the left support alone weights $p'\,\delta$.

It is easy to see *a priori* that this last strain may be deduced from the last formula of 150 by simply changing $h$ into $h'$ and $h'$ into $h$. The maxima compression of 151 is also connected with the maxima tension of the present section by virtue of the same symmetry. Indeed, if we turn the bow upside down, the lower portion of the vertical rod will become the upper, the system of diagonals will have changed, $h$ and $h'$ will have interchanged, and the signs of all the forces will also have changed. The middle rod is subject to the same considerations.

154. The preceding formulæ enable us to find easily the net cost of a simple lattice, but we shall stop to consider only the case in which the diagonals are doubled and form complete crosses.

On account of the indeterminateness of the strains in a multiple lattice, we may consider the resistance in either manner explained in 143 and 144 (rigid or flexible crosses). But, without omitting to give to the diagonals the rigidity which their theoretical section allows, by way of an additional precaution we shall follow the second method which consists in throwing the strains of compression upon the vertical rods. They will, indeed, need to be stiffened on account of their theoretical strains being more considerable than those of the diagonals, and the necessity which will nearly always exist of giving them a surplus section for the sake of the general effect of the flooring. It is obvious that if we suppose the flooring placed towards the middle of the vertical rods, the latter must possess rigidity; thus they will be able to resist compression, whether they be required to do so throughout their length or not. The diagonals, on the contrary, will require a coefficient of stiffness greater than 2; it is not too much, therefore, to double them, reckoning at each instant only upon those which resist by tension; and as additional security, those subject to compression will not remain quite useless, for they may be stiffened.

155. Before establishing formulæ of the total weight, we must point out exactly the strains which the vertical rods have to resist.

We must remark, in the first place, that under the action of a partial load moving from one of the abutments to a given point, the diagonals subjected to a tensile strain, which alone are considered as acting, will all be inclined in the same direction, from one end of the framing to the other, they will be those the feet of which are inclined towards the abutment affected by the partial load. It follows from this that, under such a mode of loading, any vertical rod may be cut by a plane which does not cross any active diagonals, and its strain will be determined as if the lattice were a simple one. The middle bar itself will come into the general formulæ, for there will no longer be in this point the forced inversion of resisting diagonals which was produced in the simple lattices with the forms adopted.

The upper portion of the rods will be calculated generally for a constant strain $(p+p')\,\frac{\delta\,h}{h+h'}$, which is no other than the tension produced under a complete load. A partial load might produce a compression equal to $\frac{p'\,\delta\,(m+n-2)}{4\,m\,(h+h')}\,[(m-n)\,(h+h')+2\,h']-\frac{p\,\delta\,h}{h+h'}$ (see 150); but in order that this strain may exceed the preceding, $h'$ must become great and $h$ small. For $h=h'$, the first formula, is sufficient so long as $m$ does not exceed the limit $\frac{1}{2}\left(3+4\,\frac{p}{p'}+\sqrt{\left(3+4\,\frac{p}{p'}\right)^2+1}\right)$; for example, for $q=0{\cdot}60$ or $\frac{p}{p'}=\frac{2}{3}$, $m$ may reach the value 5. For $h'$ nul, it is sufficient if $m$ be less than $6+8\,\frac{p}{p'}$, which is always the case, and even then it may happen that no compression is

manifested, if the permanent tension always predominates over the compressions which the load may produce. Usually $m$ is less than 5; if it exceeded this slightly, a few of the rods would be subject to a strain of compression a little greater than the tensile strain, but this small difference might be neglected on account of the surplus section which will be given in every case. We shall affect the weight of the vertical rod with a coefficient V, designed to give the rigidity necessary to resist compression and to add to the transverse stability of the structure.

If now we pass on to the lower portion of the rods, situate below the point where the load is applied to them, the strain of compression would be $\frac{(p+p')\,\delta\,h'}{h+h'}$ considering only the complete load. But under a partial load, this strain will reach the greater value (153)

$$\frac{p\,\delta\,h'}{h+h'}+p'\delta\cdot\frac{m-n+2}{4m}\cdot\frac{(m+n)(h+h')-2h}{h+h'},$$

according to which the piece should be calculated. We obtain the weight of the lower portion of the $n$th rod, by multiplying by the length and by the quantity $t$ V; and as the formula subsists for the middle rod, it will be sufficient to sum, supposing $n$ to take the successive values $1, 2, \ldots m$, then to double and subtract the value relative to $n = 1$, in order not to reckon the middle bar twice. We thus find the value given in the following section for the total weight of the lower portions of the $2m - 1$ rods.

156. Adding to the rods thus calculated the total weight of the flanges (147) and that of the two systems of diagonals (149 and 153), we shall have the total weight of the bow-girder

$$\text{Weight of the flanges} = \frac{(p+p')\,\delta\,t\,\mathrm{U}}{h+h'}\left[2m^3\delta^2+(4m-1)\frac{h^2+h'^2}{3m}\right];$$

Weight of the diagonals

$$=\frac{p'\,\delta\,t}{30m^2(h+h')}\left[30m^3(m-1)\delta^2+(h^2+h'^2)\left(16m^4-60m+59-\frac{15}{m}\right)+8hh'(4m^4-5m^2+1)\right];$$

$$\text{Weight of the vertical rods}\begin{cases}\text{Upper portion}=\dfrac{(4m^2-1)(p+p')\,\delta\,t\,h^2\,\mathrm{V}}{3m(h+h')};\\ \text{Lower portion}=\dfrac{(4m^2-1)(p+p')\,\delta\,t\,h'^2\,\mathrm{V}}{3m(h+h')}+\end{cases}$$

$$\frac{p'\,\delta\,t\,h'\,\mathrm{V}}{60m^2(h+h')}\left[h(16m^4+15m^3-20m^2-15m+4)+h'(16m^4-40m^3+20m^2+10m-6)\right].$$

Mean weight of the bow-girder a lineal mètre

$$=\frac{(p+p')\,t}{12m^2(h+h')}\left\{3m^2\,\mathrm{U}\,l^2+2(\mathrm{U}+\mathrm{V})(4m^2-1)(h^2+h'^2)+\frac{q}{10m^2}\left[15m^2(m-1)l^2\right.\right.$$
$$+2(h^2+h'^2)(16m^5-60m^2+59m-15)+16mhh'(4m^4-5m^2+1)+m\,\mathrm{V}\,hh'(16m^4$$
$$\left.\left.+15m^3-20m^2-15m+4)+2m\,\mathrm{V}\,h'^2(8m^4-20m^3+10m^2+5m-3)\right]\right\}+\Omega.$$

For the case in which $h = h'$, this formula becomes, representing the total height by H:

Mean weight a mètre of bow-girder with flanges of an equal curve

$$=\frac{(p+p')\,t}{12m^2}\left\{\frac{3m^2\,\mathrm{U}\,l^2}{\mathrm{H}}+(\mathrm{U}+\mathrm{V})(4m^2-1)\mathrm{H}+\frac{q}{10m^2}\right.$$
$$\left.\left[\frac{15m^2(m-1)l^2}{\mathrm{H}}+\mathrm{H}(32m^5-20m^3-60m^2+63m-15)+\frac{m\,\mathrm{V}\,\mathrm{H}}{4}(32m^4-25m^3-5m-2)\right]\right\}+\Omega;$$

or making $2m = \mathrm{N}$: Weight a mètre

$$=(p+p')\,t\left\{\frac{\mathrm{U}\,l^2}{4\,\mathrm{H}}+\frac{(\mathrm{U}+\mathrm{V})(\mathrm{N}^2-1)\mathrm{H}}{3\,\mathrm{N}^2}+\frac{q}{60\,\mathrm{N}^4}\right.$$
$$\left.\left[15\,\mathrm{N}^2(\mathrm{N}-2)\frac{l^2}{\mathrm{H}}+4\,\mathrm{H}(2\,\mathrm{N}^5-5\,\mathrm{N}^3-30\,\mathrm{N}^2+63\,\mathrm{N}-30)+\frac{\mathrm{N}\,\mathrm{V}\,\mathrm{H}}{8}(16\,\mathrm{N}^4-25\,\mathrm{N}^3-20\,\mathrm{N}-16)\right]\right\}+\Omega.$$

The important part played by the vertical rods, which serve in several ways, will require a high value of V.

157. *Parabolic Arched Girder, divided into an even number of intervals.*—The particular case in which $h' = 0$ gives:

Weight a mètre of arched girder

$$=(p+p')\,t\left\{\frac{\mathrm{U}\,l^2}{4\,\mathrm{H}}+\frac{(\mathrm{U}+\mathrm{V})(4m^2-1)\,h}{6m^2}+\frac{q}{m^2}\left[\frac{(m-1)\,l^2}{8h}+\frac{h}{60m^2}(16m^5-60m^2+59m-15)\right]\right\}+\Omega;$$

or, N being even: Weight a mètre

$$=(p+p')\,t\left\{\frac{l^2}{4h}\left(\mathrm{U}+\frac{\mathrm{N}-2}{\mathrm{N}^2}q\right)+\frac{2h}{3\,\mathrm{N}^2}\left[(\mathrm{U}+\mathrm{V})(\mathrm{N}^2-1)+\frac{q}{5\,\mathrm{N}^2}(\mathrm{N}^5-30\,\mathrm{N}^2+59\,\mathrm{N}-30)\right]\right\}+\Omega.$$

The observations in 144 apply here. No rod will be subject to compression if we have $p>\frac{(m-1)^2}{4m}p'$, and even when this condition is not fulfilled, the compressions may be neglected, for they are always much less than the tensions. The coefficient V is, therefore, really retained to give to the rods a rigidity which may enable us to utilize them in connecting the girders; but its value may be considerably less than in the case in which $h = h'$, of the preceding section.

158. The strains upon the pieces are easily deduced from the general formulæ. We have:

Constant maximum strain upon the lower flange $= \frac{m^2 (p + p') \delta^2}{2 h}$;

Maximum strain upon the $n$th section of the upper flange $= \frac{(p + p') \delta}{2 h} \sqrt{m^4 \delta^2 + (2n - 1)^2 h^2}$;

Maximum strain upon the $n$th diagonal (full lines) $= \frac{p' \delta}{4 m h} \sqrt{m^4 \delta^2 + (m^2 - n^2)^2 h^2}$;

Maximum strain upon the $n$th diagonal (dotted lines) $= \frac{p' \delta}{4 m h} \sqrt{m^4 \delta^2 + [m^2 - (n-1)^2]^2 h^2}$;

Maximum strain upon the $n$th vertical rod $\begin{cases} \text{tension} + (p + p') \delta; \\ \text{compression (if any)} = \frac{(m - n)(m + n - 2) p' \delta}{4 m} - p \delta. \end{cases}$

159. *Bow Bridges continued.—Examples.*—The great height which bow bridges attain renders the bow subject to compression liable to distortion in the middle of the bearing; but this height will generally enable us to use ties on the upper part without impeding the passage of the trains. The lower and upper ties, with the vertical rods, will constitute a rigid frame, binding the whole together. If the height is very great, simple gussets will be insufficient at the corners of these frames, and recourse should be had to vertical St. Andrew crosses, similar to those shown in Fig. 1770. This is the case in which it is especially necessary to give the vertical rods an excess of section, to prevent their yielding at the points to which the vertical cross-bracing is fixed.

At the end, the decrease of height allows the suppression of the upper ties without compromising the stability. In the intermediate parts, it will be prudent to place vertical rods with broad projecting ribs, firmly fixed to the horizontal portion of the bridge, as in the case of girders loaded on the lower side.

The rigidity of the whole is completed by the lower horizontal cross-bracing, and a cylindrical upper cross-bracing extending over that portion of the bridge where the height is sufficient. In this way distortion, or the strain of torsion, will be better prevented or overcome than in girders loaded on the lower side, and it may be done at a less expense than in a straight tubular bridge, in which the upper tying must extend throughout the length.

The framing, or bow-girder, should terminate at its two extremities in solid wrought-iron plates binding the two flanges together; great strength is here required, but it may be obtained without much expense, because the height is inconsiderable.

160. *Rigidity of the Bows.*—If the form of a bow-girder with a straight lower flange, or stringer, be preferred, we saw (144 and 157) that it is easy, whatever the height may be, to elude completely the compressions upon the diagonals, and almost wholly also upon the vertical rods, which, besides, are always provided with considerable rigidity. It is, therefore, useless in this case to make the bow rigid; perhaps it is wise to allow the flanges a certain flexibility, in order that the spandrils may have to maintain the form of the bow; for if the rigidity of the latter usurped this duty in too marked a manner, there would result moments of rupture in virtue of which the distribution of the pressures would be made in an unequal manner among the several sections.

In a certain degree this will always be the case, and it should be taken into account by slightly increasing the coefficient U. This remark applies also to straight girders which are not strictly articulate or jointed pieces, though calculated as such. It is advantageous to regard the two flanges as solid with each other, and furnishing a moment of resistance in virtue of which the pressure is greater upon certain fibres than upon others. The cross and the vertical bars will benefit by this circumstance, and will bear strains a little less than those given in the calculations.

It is when the moving load is great with respect to the dead weight that it is especially necessary to consider the bow-girder as an articulate system. On the contrary, if we place the resistance to distortion in the rigidity of the bow, we are obliged to increase the permanent load by means of a thick layer of ballast. The bow may then be calculated by the formulæ of the flexion of the curved pieces; the diagonals are, however, retained, but they are reduced to very slender rods; the flanges, on the contrary, are strengthened, and their section should have a considerable height. Under these conditions, the principal part will be played by rigidity; for when several pieces act together, the strain will concentrate itself upon those which are best able to resist it.

161. *Comparison between Straight and Arched Girders.*—When the height allowed is unlimited, a bridge of straight girders loaded on the upper side will have, over bow-girders, the advantage of diminishing the cube of masonry by requiring a lower bed. But if the height is limited, we have only, in making choice of a system, to compare the metallic portions.

If the bridge had to carry only the permanent load $p$, uniformly distributed throughout the length, the comparison would be exceedingly simple. Indeed, an arched girder may, in this case, be deprived of diagonals, and by giving it the most advantageous height, its weight a lineal mètre will be expressed by the following value, supposing $l = 2m\delta$:

$$\frac{P_1}{l} = \frac{p l t}{m} \sqrt{\frac{4m^2 - 1}{3}} \left( \text{for height} = \frac{m l}{2} \sqrt{\frac{3}{4m^2 - 1}} \right);$$

Neglecting all coefficients, a girder of triangles, Fig. 1657, would give for the theoretical minimum expense ($\alpha$ being equal to $\beta$),

$$\frac{P_2}{l} = \frac{p l t}{2m} \sqrt{m \left[ m + \frac{2}{3} (4m^2 - 1) \right]} \text{ with height} = \frac{l}{4m} \sqrt{1 + \frac{2}{3m} (4m^2 - 1)}.$$

| Or for $m$ = .. .. .. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| We have $\frac{P_2}{P_1}$ = .. .. | 0·866 | 1·094 | 1·298 | 1·480 | 1·638 | 1·790 | 1·920 | 2·046 |

Thus for $m = 8$, the straight girder would weigh more than twice as much as the arched girder; but this supposes that the rise of the latter is not less than 0·43 of the bearing, whilst the height of the former would not exceed 0·148.

The effect of a moving load will be to render necessary the addition of diagonals to this latter girder; but for the straight girder also the strains upon the bars will be greater than with a permanent load. Rigidity requires another increase, but more especially upon the struts of the straight girder. The arched girder will generally have a great advantage in respect to the lattice, even with heights which are not the most economical; but in order that there may be nothing to lose upon the flanges, it must have a rise $\kappa l$ greater than the height $\kappa' l$ which would be given to the straight girder. The weights of the flanges will be equal in the two systems when we have between $\kappa$ and $\kappa'$ the following relation, the coefficient U being supposed the same in both systems: $\kappa' = \frac{2\kappa(N^2-1)}{3(N^2-1)+8N^2\kappa^2}$, in the case of N odd; or

$$\kappa' = \frac{2\kappa(N^2-1)}{3N^2+8(N^2-1)\kappa^2}, \text{ if N is even.}$$

N has, however, but a small influence; if for the straight girder we take $\kappa' = 0.10$, we shall have $\kappa'$= about 0·16; for if $\kappa' = \frac{1}{8}$, the rise would be 0·21 of the bearing.

In general, with the rise allowed in practice, we ought not to reckon upon saving in the flanges, but the advantage of the arched form will be essentially in relieving the vertical portion (see 168).

162. *First Example.—Arched Girder with Simple Rigid Diagonals*, Figs. 1761 to 1765.—Data: $l = 36^m$, $p = 2000^k$, $p' = 3300^k$, $p + p' = 5300^k$, $q = 0{\cdot}623$; $\delta = 4^m$, N = 9, or $m = 4$, $h = 6^m{\cdot}50$.

The lower flange supports, under a load, a constant strain of 130½ tons. It is composed of three angle-irons of $\frac{100/100}{12}$ millimètres, a vertical rib of 550/10, to which the vertical bars are fixed by twelve rivets of $0^m{\cdot}025$, and two horizontal plates of 600/10 each.

The upper flange supports strains expressed by $\frac{(p+p')\delta}{2h}\sqrt{m^2(m+1)^2\delta^2+4(n-1)^2h^2}$, which vary from 130½ tons in the middle ($n = 1$), to 155·6 tons in the extreme section ($n = 5$).

The vertical rods have a maximum tension which varies from 30 to 21·2 tons. The first may, besides, be compressed by a force equal to $\frac{p'\delta}{2(2m+1)}(m-n)(m+n-1) - p\delta = 800^k$ only, and for the others the strain is always one of tension. The vertical rods are therefore strengthened only with a view to the stability of the whole flooring. The two girders, or framings, are bound firmly together in two places towards the middle of the bearing by tie-beams so arranged as to form a rectangular figure enclosing the whole bridge.

The strain upon the diagonals (139) varies from 17·2 tons for the first (middle) to 10·8 tons for the last ($n = 4$). The first is divided into two portions to form a cross, each arm of which supports only 8·6 tons. The sections adopted have sufficient rigidity, regard being had to their strain a unit of section, which strain is very small.

Calculation gives:

| | | | |
|---|---|---|---|
| Flanges | Angle-irons and vertical ribs, with their joint-plates and solid ends | 10500$^k$ | 18800$^k$ |
| | Horizontal plates with their joint-plates .. .. .. .. .. .. | 8300 | |
| Vertical rods .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. | | 2130 | |
| Diagonals .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. | | 1800 | 4200 |
| Two horizontal pieces of railing and central gusset .. .. .. .. .. | | 270 | |
| Total .. .. .. .. .. .. .. .. .. .. .. | | | 23000$^k$ |

Say 612 kilogrammes a lineal mètre (of the whole length $37^m{\cdot}60$).

The formula of 141 becomes, with the data of the present example, and adding a special term for the addition to the vertical rods,

$$\frac{P}{l} = 369\,U + 22{\cdot}6\,V + 38{\cdot}5 + 7{\cdot}04\,\theta + \Omega.$$

The flanges weighing $\frac{18800^k}{37^m{\cdot}60} = 500^k$ a mètre, we shall have $U = \frac{500}{369} = 1{\cdot}35$, including the plates at the ends. These latter having an excess of strength, the value of U may be reduced a little.

For the diagonals, $V = \frac{50}{22{\cdot}6} = 2{\cdot}21$.

The vertical rods weigh, according to the calculation, about 60 kilogrammes a lineal mètre of girder: the theoretical weight being only 38·5, we have to cover $21^k\ 5$ by means of a term $\theta$ requiring $\theta = 3$; in other words, the excess of section given to the rods is equivalent to the addition of a projecting piece weighing $\theta h = 19^k{\cdot}5$ a mètre (of its own length).

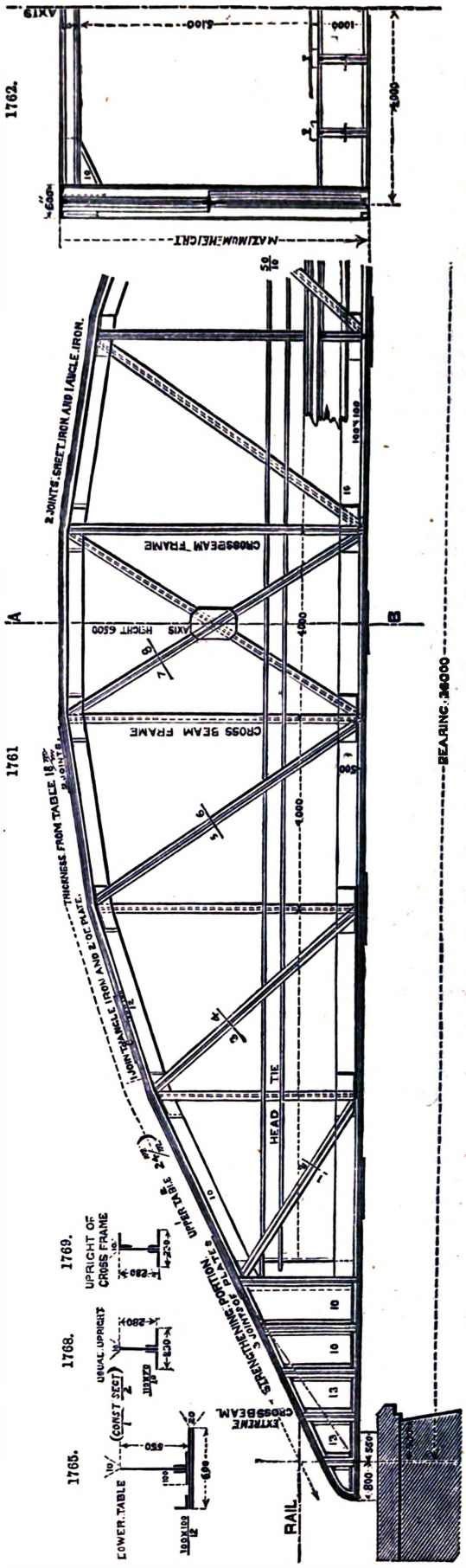
$\Omega$ is here only $\frac{270}{36} = 8$ kilogrammes (say 0·013 of the total weight).

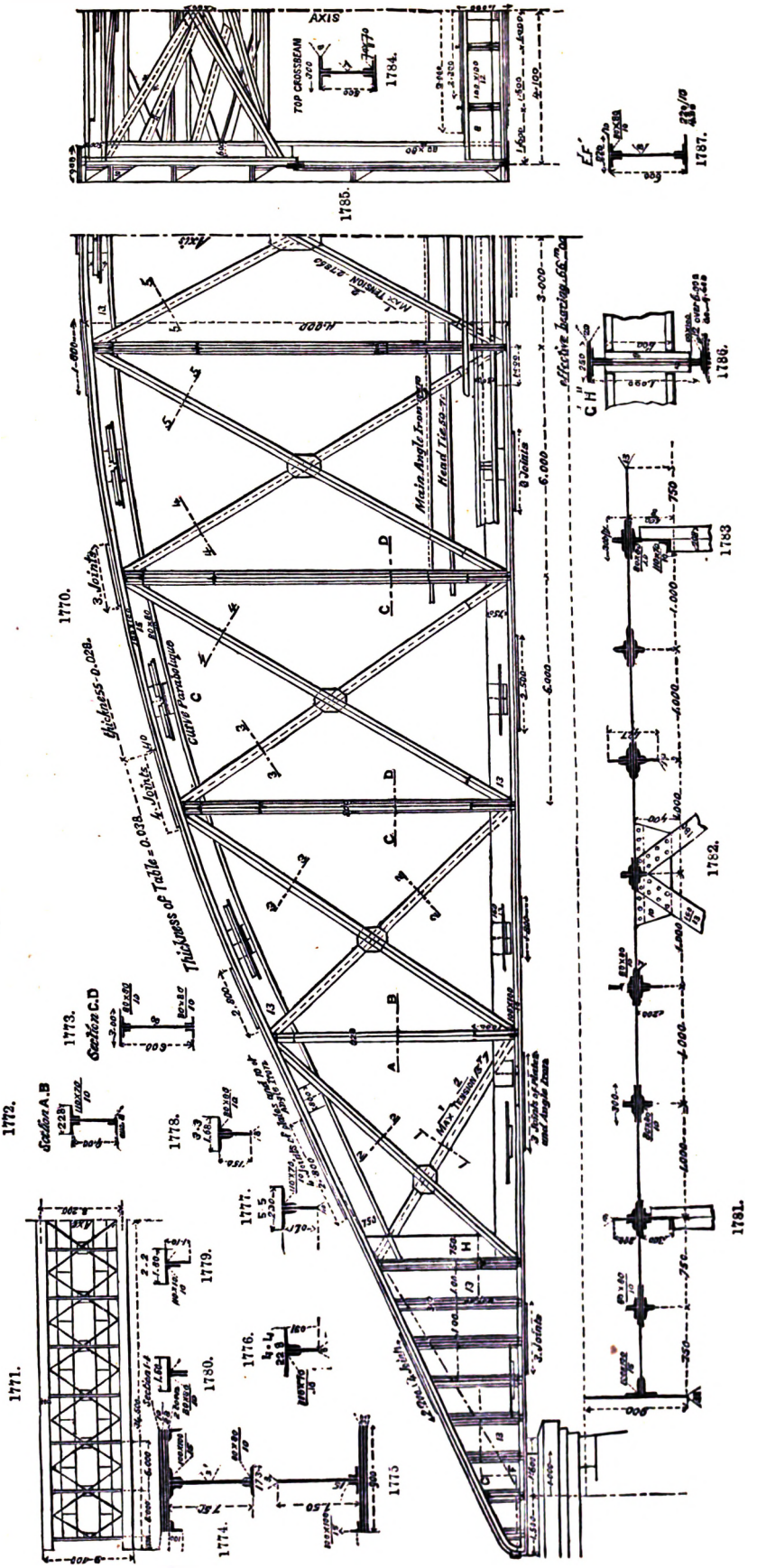
163. If double diagonals were adopted, we might leave the vertical rods unchanged, since they are determined by other conditions than the theoretical strain; and the double diagonals, calculated for tension only, would give a weight of 58 kilogrammes a mètre. Thus, in this example, the single diagonals, though V is a little greater than 2, give a small advantage, which is due to the fact of their having been chosen short, and exposed to the least strain. The saving is, however, so trifling that it would have been quite as advantageous, and perhaps more so, to adopt the cross. This will be done in the following example.

164. *Second Example.—Arched Girder of Tension-crosses*, Figs. 1770 to 1787.—Data: $l = 66^m$, $p = 2500^k$, $p' = 3000^k$, $p + p' = 5500^k$, $q = 0{\cdot}545$, $\delta = 6^m$, $N = 11$, or $m = 5$, $h = 11$.

As in the preceding example, we shall adopt a moderate load, for the value $p' = 4000$ corresponds with the purely fortuitous case of two heavily-laden trains crossing the bridge at the same time.

The lower flange bears, under a complete load, a constant tension of 270 tons; the upper, 270 in the middle to 316·5 tons at the end; or more correctly, this last strain will be less, for towards the ends the bow ceases to be parabolic and terminates by tangents, for the purpose of lengthening sufficiently the bearing upon the rollers.




1770.
1771.
1772.
1773.
1774.
1775.
1776.
1777.
1778.
1779.
1780.
1781.
1782.
1783.
1784.
1785.
1786.
1787.
Section A.B
Section C.D
Thickness of Table = 0.038
Curve Parabolique
Main Angle Iron
Head Tie
Max Tension
Max Tension
Axis
TOP CROSSBEAM
effective bearing

Regarding the diagonals as resisting only by tension, so that one arm only of each cross acts under a given load, the strains will be:

| | | | | | |
|---|---|---|---|---|---|
| Short diagonals .. .. | No. 1 (middle) | 2 | 3 | 4 | 5 |
| Long diagonals .. .. | Nos. 1 and 2 | 3 | 4 | 5 | 6 |
| Strain .. .. .. .. | 27·860 | 26·540 | 23·764 | 19·904 | 15·690 |

The sections adopted have a form possessing considerable rigidity. If they had been made to resist compression for the half of the load, the maximum strains would have been the half of the above, so that the sections adopted would give at least V = 2, which would warrant us in increasing to 50 the ratio of the length to the reduced thickness, a condition which is not far from being fulfilled. The spandrils are thus susceptible of two modes of resistance; the one which will be produced will be an intermediate mode, in virtue of which the strains will be less than those provided for.

The vertical rods bear 33 tons under a full load. They always resist by tension, except the first towards the middle, which may be subject to a strain of compression of 1·345 ton only. Their sections are, however, increased to give rigidity to the rectangular figure formed by the tie-beams already alluded to, to which the vertical cross-bracing is fixed.

Direct calculation gives the following results:—

| | | | |
|---|---|---|---|
| Flanges | Angle-irons with vertical ribs with their joint-plates and the end plates | 27550ᵏ | 67000ᵏ |
| | Horizontal plates with their joint-plates .. .. .. .. .. .. .. | 37400 | |
| | Gussets between the vertical rib and the horizontal plate, angle-iron on the edge of upper flange .. .. .. .. .. .. .. .. .. .. | 2050 | |
| Vertical rods (including 330ᵏ for joint-plates and other accessories required in fixing) .. | | | 8100 |
| Diagonals (including 1100ᵏ for joint-plates, filling-plates at the points of crossing) .. .. | | | 7250 |
| Railing .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. | | | 650 |
| Total .. .. .. .. .. .. .. .. .. | | | 83000ᵏ |

Say 1203 kilogrammes a mètre of the total length 69 mètres.

The formula of 145 becomes in the present case $\frac{P}{l} = 754{\cdot}5\,U + 52{\cdot}5\,V + 97 + \Omega$. The flanges weigh $\frac{65000^k}{69^m} = 942$ kilogrammes a lineal mètre of girder, which gives U = 1·25. For the vertical rods we have V = about 2·25. These quantities do not include the accessories independent of $h$, the details of which are as follows:—

| | | | |
|---|---|---|---|
| Accessories forming a part of the flanges .. .. | 2050 | 3880ᵏ, | |
| „ „ „ vertical rods .. | 330 | | |
| „ „ „ crosses .. .. | 850 | | |
| Railing .. .. .. .. .. .. .. .. .. .. | 650 | | |

which gives Ω = 57 kilogrammes a mètre of the total length, or 0·0475 of the total weight.

To discuss the height $h$, suppose that with the present data we have to adopt $V = 0{\cdot}205\,h$ (for a height above 5 mètres), and that the value U is regarded as nearly constant. The weight of the girder (145) may be put in the form $\frac{P}{l} = 7{\cdot}15\left(\frac{1392}{h} + 1{\cdot}624\,h + 0{\cdot}137\,h^2\right) + 57^k$. It becomes then a minimum for $h = 15^m{\cdot}50$, which brings it down to 1115 kilogrammes, instead of 1208 kilogrammes, which the same formula gives for the height adopted of 11 mètres.

165. To compare the arched girder with the bow properly so called, having an equal height in the middle, let us take for example the data: $l = 60^m$, N = 10, $p + p' = 5500^k$, $q = 0{\cdot}55$, total maximum height = $10^m$, U = 1·25, V = 2 for the arched girder.

We must first ascertain what value of V will be required for the bow-girder having flanges of an equal curve. Now the upper portion of the vertical rods has as a constant maximum strain 16½ tons, whilst the lower portion may be subject to strains of compression varying from 30 to 21·9 tons. The vertical rods of the arched girder will have to resist loads less than 33 tons, but in the present case the rigidity to resist compression is necessarily in the lower portion; but it is not this condition even which fixes the limit, the rods must be stronger than theory requires on account of the duty they have to perform as mediums between the girder and the flooring. We shall, therefore, give them a section at least equal to that adopted for the arched girder, which leads to a coefficient V′ equal to about 3.

The term Ω has also a more disadvantageous value in the case in which both flanges are curved, on account of the longitudinal girder which will always be required on a level with the flooring, though it is not strictly indispensable. Let us take, for example, Ω = 55 for the arched girder, and Ω = 120 for the girder with both flanges curved.

Then the formulæ of 156 (for $h = h'$) and 157 ($h = 0$) give respectively for the example under consideration:

Weight of the mètre of bow-girder with both flanges curved = 1137 kilogrammes.
Weight of the mètre of arched girder with a straight lower flange = 1092 „

Thus, with an equal total height, the simple arched form, which is the more convenient, is to be preferred. Yet it is possible that the double curve form may become the more advantageous in certain cases in which it may be regarded as warranting a greater total height, on account of the

triple tying on three different levels, provided this additional tying do not consume all the saving effected in the girder itself.

166. The last plan, Fig. 1770, gives us U smaller and Ω greater than the first example. But we may, to make the matter more simple, bring them to about the same values: to do this we may include in U the accessories forming part of the flanges, so that the latter will amount to 67000 kilogrammes (164); consequently, U will be equal to 1·29, instead of 1·25, and Ω to 0·022 of the total weight, instead of 0·0475. Already, in section 102, we have similarly attributed to U the angle-irons upon the edge of the flanges and the plates at the ends of the cross-girders, although strictly speaking these accessories do not depend upon the height, but rather upon the particular form of the flanges.

167. Admitting generally $h = 0{\cdot}18\,l$, U = 1·30, V = 2·50, and Ω = 0·025 of the weight, we may form Table X. of the quantities $\frac{P}{(p+p')\,l^2}$ for various values of N and $q$, and for arched girders with crosses. The numbers of this Table, being multiplied by $(p+p')\,l$, will give the mean weight of the lineal mètre. They have been calculated by means of the formulæ in sections 145 and 157, which, with the data admitted, become respectively

$$\frac{P}{(p+p')\,l^2} = 0{\cdot}0030135 - \frac{0{\cdot}0024}{N^2} + \left[0{\cdot}00185\,\frac{N^2-1}{N^3} + 0{\cdot}000032\left(N + \frac{1}{N}\,\frac{30\,(N-1)}{N^2\,(N+1)}\right)\right] q,$$

for N odd; and

$$\frac{P}{(p+p')\,l^2} = 0{\cdot}0030135 - \frac{0{\cdot}0006}{N^2} + \left[0{\cdot}00185\,\frac{N-2}{N^2} + 0{\cdot}000032\left(N - \frac{30\,(N^2+1) - 59\,N}{N^4}\right)\right] q,$$

for N even. Ω is included in the numerical quantities, which have been multiplied by 1·025.

168. For girders carrying a whole line of rails, we may allow :—

| | | | |
|---|---|---|---|
| For $l$ = .. | Mètres. 20 | Mètres. 60 | Mètres. 80 |
| $p + p'$ = .. | Kilos. 6900 | Kilos. 6700 | Kilos. 7300 |
| And $q$ = .. | 0·72 | 0·60 | 0·55 |

Supposing besides, as in 92, N = 7 for bridges of 20 mètres, 8 for those of 30 to 60 mètres, 9 for 70 mètres, and 10 for 80 mètres, we may draw up the following Table :—

| $l$ = .. .. .. .. .. .. .. .. .. .. | Mètres. 20 | Mètres. 30 | Mètres. 40 | Mètres. 50 | Mètres. 60 | Mètres. 70 | Mètres 80 |
|---|---|---|---|---|---|---|---|
| Weight of the mètre of girder carrying a whole line of rails .. .. .. .. .. .. .. | Kilos. 460 | Kilos. 680 | Kilos. 890 | Kilos. 1100 | Kilos. 1310 | Kilos. 1600 | Kilos. 1900 |

These weights differ but little from those of girders of simple triangles (92), or of crosses without vertical rods (105); so that the advantage of the arched form is not in the girder itself, but consists merely in diminishing the length over which the upper tying and cross-bracing extends. Over other systems of girders the advantage in weight will be more sensible; but it may happen that the builder asks a higher price the kilogramme for structures with curved flanges than for those with straight girders. In this case the price must be taken into consideration in comparing the relative merits of the several systems.

As the arched form allows the rigidity of the vertical portion to be relegated to the rank of secondary questions (144 and 157), an arched girder carrying only one rail will weigh but little more than half of the weights given above for girders loaded with a whole line. Therefore, in the case of a small load, the advantage of the arched form becomes more decided.

We will repeat once more a remark already made several times: it is that, in general, in order that a girder may support wholly the load of one line of rails, we must consider the case of two heavy trains crossing at the same time; if, therefore, for this fortuitous case we are willing to raise slightly the value of R, we may reduce the weights given above.

181. *Weight of the Lineal Mètre of Railway Bridges carrying Two Lines of Rails.—Case of Limited Height.*—When the depth between the level of the rails and the lower side of the girders is limited, the system of loading the girders upon the lower side is resorted to, which for long spans is developed into the tubular system.

A.—*Three-girder Bridges loaded on the lower side.*—If the depth allowed, though limited, is yet sufficient to enable us to give to the cross-girders a height of $0^m{\cdot}70$ or $0^m{\cdot}80$; these, added to the minor longitudinal girders will make up a weight of about 640 kilogrammes the lineal mètre of flooring under two lines of rails, the distance apart being included between 3 and 5 mètres. In detail :—

With a distance apart of 3 mètres and a height of $0^m{\cdot}70$, we should have .. } Cross-girders = $375^k$; minor longitudinal girders = $265^k$. Total = $640^k$.

And with a distance apart of 5 mètres and a height of $0^m{\cdot}80$, we should have } Cross-girders = $250^k$; minor longitudinal girders = $385^k$. Total = $635^k$.

For spans of 30 mètres and above, a horizontal cross-bracing is added, weighing from 80 to 100 kilogrammes the mètre of flooring; and in that case the total of the pieces and the chief girders will increase to 720 or 740 kilogrammes.

If the height of the girders exceeds 5 mètres, we shall adopt the tubular system by adding tie-beams at the top reckoned at 90 or 100 kilogrammes, Fig. 1719, and an upper cross-bracing reckoned at 70 or 90 kilogrammes. The total will be from 880 to 930, according to the span. The upper tie-beams increase but little with the span; for if, in a large bridge, they are increased in size, they may be placed farther apart.

The outside girders carry only one rail, and should never be subjected to a strain greater than 6 kilogrammes the square millimètre; but the middle girder may support a whole line in the case of two trains crossing the bridge at the same time, an exceptional circumstance when the strain may without injury be raised to $7^{k}\cdot50$, especially as the loads supposed (34) are for very heavy trains. In the ordinary case of the passage of one train, the middle girder will not be subject to a strain of 6 kilogrammes. In virtue of this increase of R, the weight of the girder, or at least the part which is a function of $t$, will be reduced to $\frac{4}{5}$; or, which amounts to the same thing, $t$ will have the value 0·00104, instead of 0·0013. If the height be not changed, something will yet be gained by the fact that the lightening of the girder diminishes to an equal amount the load which it bears.

Girders loaded on the lower side are badly supported if their height is great without being sufficient to allow an upper tying. The heights between $3^{m}\cdot50$ and 5 mètres should, therefore, be avoided. For example, if the height theoretically the most favourable were 4 mètres or under, it should be reduced to about $3^{m}\cdot30$; if it were above 4 mètres, it should be increased to $5^{m}\cdot80$, in order to adopt the tubular system. However, if the depth allowed will permit, we may sometimes raise the cross-girders as shown in Fig. 1718, in a two-girder bridge, and in that case we may without inconvenience retain the height calculated.

182. Table XII. A gives the weights of three-girder bridges calculated according to the preceding indications. An addition of $\frac{1}{10}$ has been made to include unforeseen necessities. Multiplying the weight of the lineal mètre of total length by 1·045, we obtain the weight a lineal mètre of bearing (37), given in the last column. Multiplying this last by 1·05, or immediately those of the preceding column by 1·0973, we obtain the weight a mètre of clear span between the abutments.

In the case of multiple lattices, we suppose that the outside girders have single vertical rods placed upon the inside of the girder, and that they may be computed by a mean between the weights of 117 and 118, at least when the height does not differ too widely from that of $0\cdot11\,l$, which was supposed in the sections referred to. The middle girder will have double vertical rods and a flat lattice if there is no upper tying; if the bridge is tubular, it will, on the contrary, have a rigid lattice and no vertical rods.

In arched girders, the upper tying extends only over those portions where the height is sufficient; so that its mean weight is less than in straight bridges. But in long spans this economy diminishes, and is compensated by the necessity of placing struts or St. Andrew crosses forming a vertical cross-bracing. The weights given in the Table include these circumstances.

183. If the depth allowed be very limited, we shall not be able to give the cross-girders the height supposed in 181. If, for example, we are obliged to restrict this height to $0^{m}\cdot35$, as shown in Fig. 1592, the weight of the lower cross-girders and longitudinal girders will be increased to 960 kilogrammes the mètre of flooring, instead of 640. We must, therefore, increase by 320 kilogrammes the numbers of the fifth column of Table XII. A, by 350 those of the following, and by 370 those of the seventh or last column.

The limit in height may be still less, and may require more expensive arrangements, such as those of Fig. 1591. In these cases we must of necessity adopt the three-girder system; for that of two girders, which we are about to consider, does not allow the height of the cross-girders to be decreased to such an extent.

184. B.—*Two-girder Bridges loaded on the lower side.*—When the cross-girders can be of a good height we may reckon as a mean for their weight, joined to that of the longitudinal girders, upon 750 kilogrammes the mètre of flooring. In detail:—

With a distance apart of 3 mètres and a height of 1 mètre, we have .. .. } Cross-girders = $530^{k}$; minor longitudinal girders = $240^{k}$. Total = $770^{k}$.

With a distance apart of 4 mètres and a height of 1 mètre, we have .. .. } Cross-girders = $410^{k}$; minor longitudinal girders = $320^{k}$. Total = $730^{k}$. Fig. 1600.

With a distance apart of 4 mètres and a height of $0^{m}\cdot80$, we have .. .. } Cross-girders = $425^{k}$; minor longitudinal girders = $320^{k}$. Total = $745^{k}$. Fig. 1708.

With a distance apart of 5 mètres and a height of 1 mètre, we have .. .. } Cross-girders = $340^{k}$; minor longitudinal girders = $360^{k}$. Total = $700^{k}$.

Above 30 mètres span, a horizontal cross-bracing must be added, estimated at 60 or 80 kilogrammes. Total 810 to 830, according to the span.

When the bridge becomes tubular, 170 kilogrammes must be added for upper tie-beams, and 70 kilogrammes for upper horizontal cross-bracing, in long spans these pieces are strengthened, and, in a case of necessity, vertical cross-bracings would be added; but, at the same time, the distance of the cross-pieces apart may be increased. We shall reckon, for all the pieces, as well as for the principal girders, 1050 to 1100 kilogrammes, according as the span varies from 40 to 80 mètres.

In arched girders the upper tying extends only over a fraction of the length, but this fraction increases with the span, while the vertical cross-bracing acquires at the same time more importance: therefore in long spans the secondary pieces weigh as much as in straight girders.

When there is but one train upon the bridge, the girder subjected to the greatest strain will sup-

port only about $\frac{3}{4}$ of the load of a whole line, and under these circumstances we may subject it to a strain of 6 kilogrammes, since on the exceptional hypothesis of two heavy trains being on the bridge at the same time, the maximum strain will still be less than $7^{k}\cdot50$. The weight of girders may, in general, be rapidly calculated by interpolation. For example, for a solid girder of 20 mètres span, we may reckon $p = 1800$ kilogrammes (including 500 kilogrammes for the girder itself); $p' = \frac{3}{4}$ of a line of rails $= 3750$; total, $p + p' = 5550$ kilogrammes. Now the Table of 129 gives 370 kilogrammes for a girder carrying one rail, and the load of which was valued at 3600 kilogrammes, and 570 kilogrammes as the weight of a girder carrying two rails, and for which we had supposed $p + p' = 7000$. Interpolation will give for the present case

$$370 + 200 \cdot \frac{5550 - 3600}{7000 - 3600} = 485 \text{ kilogrammes.}$$

The height, interpolated between $1^{m}\cdot70$ and $2^{m}\cdot25$, would be about 2 mètres. In these cases, in which the height thus found would have to be modified considerably to prevent its falling between $3^{m}\cdot60$ and $5^{m}\cdot60$, for reasons already stated, the weight would be calculated directly by the formulæ, with suitable values of U and V.

Table XII.B gives approximative weights for two-girder bridges constructed according to the hypotheses which have just been made. The multiple lattices are supposed to be with single vertical rods, which allows one of the systems of bars at 45° to be constructed of pieces with projecting ribs.

185. In the case in which it is required to decrease to $0^{m}\cdot60$, for example, the height of the cross-girders, in consequence of the limited depth, we shall have to increase by a constant equal to about 300 kilogrammes the numbers of the third column of Table XII.B. The following column, including an addition of $\frac{1}{10}$, will increase by 330 kilogrammes; and the weights of the last column will be augmented by 345 kilogrammes.

186. *Case of Unlimited Height.*—When the height allowed is unlimited, we are none the less free to adopt one of the preceding systems, but we have the advantage of placing the girders entirely below the level of the rails, which will give rise to other systems: these systems we are about to consider. They may be preferred, if they are found to be more economical, and it may be at once remarked that they possess an advantage in requiring a lower bed of masonry. The fact of the bed being far removed from the plane of vibration may appear detrimental to the stability of the structure; but this may be remedied by means of vertical cross-bracing, especially that which is placed above the supports.

187. C.—*Four-girder Bridges under Rails.*—According to Figs. 1612, 1614, supposing a distance of 3 mètres between the cross-girders, we may reckon from 260 to 345 kilogrammes a mètre of flooring for the pieces other than the principal girders, and the horizontal cross-bracing, according as the height of the girders varies from $1\cdot50$ to 4 mètres; say 300 to 400 kilogrammes, including the horizontal cross-bracing.

The girders carry each one rail, and their weight is found ready calculated, according to their mode of construction, in the Tables of sections 92, 105, 106, 117, 118, 129, 133.

Table XII. C gives the weight a mètre of four-girder bridges for spans of 20 to 50 mètres, for this system will never be adopted for very long spans.

188. D.—*Three-girder Bridges under Rails.*—According to Figs. 1605 and 1618, 1619, the pieces other than the principal girders and the horizontal cross-bracing will weigh from 460 to 620 kilogrammes, according as the height of the girders varies from 2 to 5 mètres. As in the preceding case, the resisting breadth of the flooring hardly exceeding 5 mètres, it is necessary to have recourse to horizontal cross-bracing beyond 20 mètres span; reckoning it at 40 to 60 kilogrammes, we shall have a total of 500 to 680 kilogrammes for heights of 2 to 5 mètres.

Beyond 50 mètres span, it is preferable to increase the distance between the outside girders by adopting the second arrangement, Fig. 1619: we may then reckon upon $830 + 70 = 900$ kilogrammes for a span of 50 mètres to 1100 kilogrammes for a span of 80 mètres.

Each girder will be calculated for a permanent load $p$ equal to its own weight a mètre, increased by 700 to 900 kilogrammes. As to $p'$, it may be estimated at $\frac{7}{5}$ of a rail, for an outside girder, if the distance apart is 5 mètres, and at $\frac{7}{6}$ of a rail if the girders are arranged as in Fig. 1619 (second arrangement). For the middle girder, $p'$ will be, in the same cases, respectively equal to $\frac{6}{5}$ or to $\frac{5}{3}$ of a rail, both lines being loaded simultaneously by heavy trains. For this exceptional case we may raise R to $7^{k}\cdot50$, or reduce $t$ to $0\cdot00104$, for then the maximum strain will always be less than 6 kilogrammes a square millimètre in the ordinary case of one line loaded, in which $p'$ would be reduced by one-half.

It is possible to give different heights to the middle and to the outside girders, but the advantage of this complication is too small to render it worthy of adoption.

Table XII.D gives approximative weights for bridges constructed according to this system.

189. E.—*Two-girder Bridges under Rails.*—Fig. 1615 would give 560 kilogrammes a mètre, for the pieces other than the principal girders, including 60 kilogrammes for the horizontal cross-bracing, the height of the girders being $2^{m}\cdot50$. With a height of 3 mètres, and taking the

arrangement of Fig. 1606, we may reckon 600 kilogrammes: Fig. 1742 would give 660 kilogrammes, the height of the girders being $4^m \cdot 50$.

With the first kind, in which the distance between the girders is 5 mètres, we shall take from 550 to 700 kilogrammes, according as the height varies from 2 to 5 mètres.

Beyond a span of 40 mètres, it is better to widen the flooring by adopting the arrangement shown in Fig. 1580. We may then reckon, for the pieces other than the principal girders, from 800 to 1000 kilogrammes, including the horizontal cross-bracing, according as the height varies from 4 to 9 mètres.

Each girder is calculated for a strain R = 6 kilogrammes a square millimètre, taking for $p$ the weight of the girder itself increased by 1000 to 1200 kilogrammes, according to the span, and for $p'$ the load of 1·70 or 1·55 of a rail, according as the distance between the girders is 5 or 6·40 mètres. These values relate to the case of only one line loaded; but in the case of two heavy trains passing each other upon the bridge, R will not exceed 7 kilogrammes.

Table XII. E gives weights for two-girder bridges, a mètre, increased by $\frac{1}{10}$.

In all the systems of girders loaded on the upper side, vertical rods will be quite unnecessary.

190. *Comparison of the several Systems.*—On comparing Tables XII. A, XII. B, XII. C, XII. D, and XII. E, we see immediately the advantage of reducing the number of girders to two, especially in the case of long spans. But when the depth allowed is limited to the absolute minimum, the system of three girders (Table XII. A) becomes the only possible one. When the height is unlimited, the two-girder bridge loaded on the upper side (Table XII. E) is preferable to the two-girder bridge loaded on the lower side (Table XII. B); but in long spans, this latter system will be generally more advantageous than those of four or of three girders (Tables XII. C and XII. D).

As to the mode of constructing girders considered by themselves, the solid form is the most expensive: then come multiple, triangular, and cross lattice-girders, and last, cross-lattice arched girders. However, in two-girder bridges loaded on the lower side (Table XII. B), the arched form offers but a trifling advantage in weight over the straight form with cross-lattice, and it is besides more complicated in construction. Compared with a straight girder with multiple lattice, it has again a certain advantage: for example, for a two-girder bridge of 60 mètres span, it would offer a total saving of about 44 tons; but if there were a difference in price, and the arched-girder bridge were paid for at the rate of 0·70 franc, for example, a kilogramme, whilst the straight-girder bridge cost 0·60 franc, the saving would be reduced to 4000 francs.

To make the comparisons more evident and palpable, we might represent graphically the weights given by the Tables.

191 α. *Observation.*—In using the Tables, care must be taken not to lose sight of the hypotheses on which the calculations are based. Thus, there will be no ground for surprise that the bridge represented by Fig. 1708 weighs 4335 kilogrammes a mètre, whilst Table XII. would give a less weight: this apparent anomaly proceeds from the fact of our having calculated that structure for a heavier load, on the supposition that R should never exceed 6 kilogrammes, even in the exceptional case of both lines loaded simultaneously. So in the two-girder tubular bridge, Fig. 1690, calculated for $p + p' = 7000$, the span being 56 mètres, the weight of a girder reached 1300 kilogrammes a mètre, whilst by interpolating in Table XII. B we should compute it at 1080 kilogrammes only; but this is because, according to the hypotheses of this Table, the load considered for a strain of 6 kilogrammes is only $\frac{3}{4}$ of a line of rails, and, besides this, the permanent load, reduced to its just value by taking into account the lightening of the girder, is, by 400 or 500 kilogrammes, smaller than the value liberally computed in section 89. And, indeed, if we multiply 1300 kilogrammes by the ratio of the loads supposed, say about $\frac{5550}{7000}$, we obtain 1030 kilogrammes, which is not quite so much as the Table gives. In the same bridge, calculation had given also a slightly greater weight for the flooring, because the cross-girders had been reduced to a height of $0^m \cdot 70$.

191 β. Bridges of 10 mètres span and less are always of solid girders, this form being simpler and more advantageous for an inconsiderable height. The best arrangements in these small structures are, in general, easily discovered, and ready-made plans exist in abundance. In the case of very limited depth, we may adopt the hollow form of girder, if the bearing does not exceed 5 or 6 mètres. Beyond that, the three-girder system, with minor longitudinal girders of the hollow or of the double ⊤ form, will be the best. And when the height permits, we may take the bridge of four girders, one under each rail, with very light tie-beams.

If the depth is unlimited, it is sufficient to reckon from 600 to 1200 kilogrammes (including parapet) as the weight of a flooring under two lines of rails, a mètre of bearing, according as the latter varies from 3 to 10 mètres. In the case of very limited depth, these figures must respectively be increased to 1000 and 2000 kilogrammes, if a general notion, only, of the expense is required.

192. *Weight of Road Bridges.*—When there are inclined struts, as in Figs. 1607 to 1611, and 1625, care must be had to take into account the increase of weight which they occasion when the height increases. For instance, in the last of these three figures, we may suppose that the weight of the pieces other than the principal girders is represented by $720 + 50\,h$, $h$ being the height of the girders.

For the kinds shown by Figs. 1625 and 1788, 1789, which are applicable to small spans, solid girders from 0·70 to 1 mètre high should be adopted; the joints in the vertical rib should be far apart, indeed there should be only one in spans of 10 mètres; the vertical stays or stiffening rods should consist of single angle-irons, serving to fix the cross-girders and brackets. For other kinds, it will be advantageous to employ multiple lattice-girders, or, better still, cross lattice-girders; these girders should in general be provided with vertical rods for the purpose of affixing the cross-girders and brackets, but often it will be sufficient to give them a small sectional area: it was seen in

108 to 118, that in multiple lattice-girders it is advantageous to use single vertical rods, that is, rods upon one side only of the lattice, in order that one at least of the systems of oblique bars may have projecting ribs.

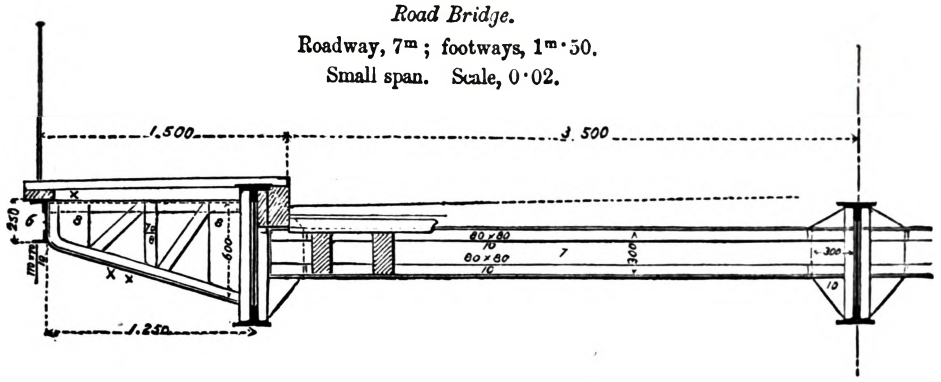
In three-girder bridges, the middle girder is more heavily loaded than the outside ones, and, when nothing prevents, it will be well to give it greater height; this is easily done in the case of girders loaded on the lower side; when the height is unlimited, as in Fig. 1609 for example, the bed-plate of the middle girder may be placed at a lower level than those of the outside girders. It is in the kind of bridge represented in Fig. 1626 that the difference in the load upon the girders is especially great; when the bridge is tubular, the upper tie-beams may be arched, and the middle girder raised.

1788.

*Road Bridge.*

Roadway, 7m; footways, 1m·50.

Small span. Scale, 0·02.




1789.

*Road Bridge.*

Roadway, 10m; footways, 2m.

Small span. Scale, 0·02.

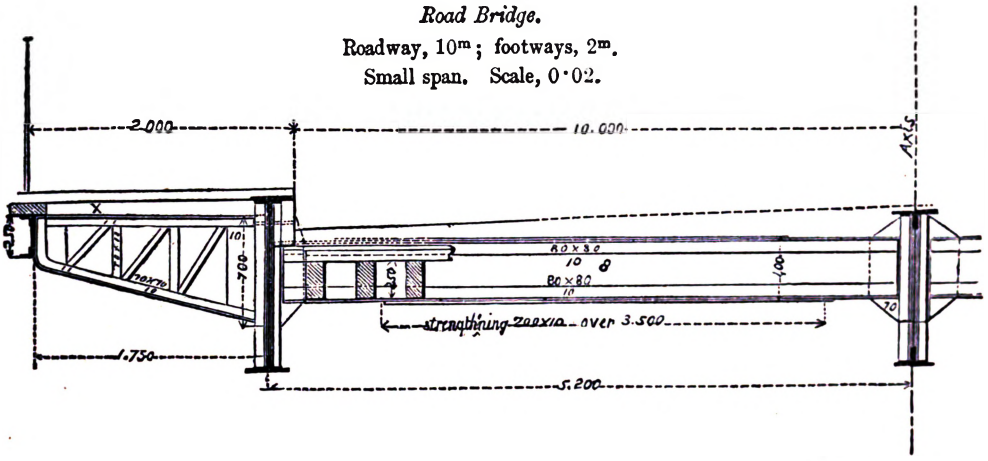
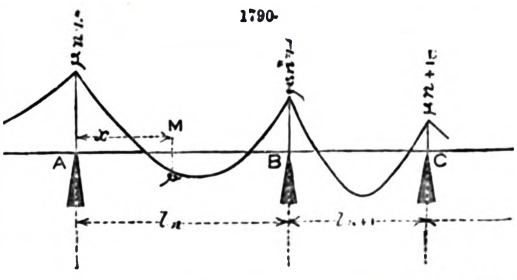



Table XIII. gives some general values of weights for roads of 6, 10, and 14 mètres broad, and for spans of 10 to 50 mètres.

In long spans a considerable saving may be effected by suppressing the ballasting, which will diminish the permanent load. This may be done without danger, because vibration is much less to be feared than in railway bridges, where the moving load is driven at greater velocities, and the ratio $q$ usually possesses a value near 0·60; whilst in a road bridge where the ballast would have a mean thickness of 0m·20 (35), $q$ would be about 0·40. In any case, if the ballasting is retained, it is evident that the cross-bracing will be much less important in a road bridge than in a railway bridge.

193. *Bridges of several Bays.*—When a continuous girder rests upon several supports, and carries a load uniformly distributed throughout a bay, but liable to vary from one bay to another, the locus of the moments of rupture, in any bay in which the load is $p_n$ a mètre, will always be a parabola with a vertical axis, having as a parameter $\frac{1}{p_n}$, and the position of which will be determined by the condition of passing through the summits of the ordinates which, raised upon the supports limiting the bay under consideration, will represent the moments of rupture in a line with these supports. Thus for the bay A B of Fig. 1790, the length being $l_n$, the load a mètre $p_n$, the moments of rupture upon the supports A and B

1790.



being $\mu_{n-1}$ and $\mu_n$, we shall have as the variable moment in the point M, the abscissa of which is $x$ reckoning from A, the expression

$$\mu = -\frac{p_n x^2}{2} + \left(\frac{p_n l_n^2}{2} + \mu_n - \mu_{n-1}\right)\frac{x}{l_n} + \mu_{n-1};$$

and the stress in the same point will be the derivative

$$F = -p_n x + \frac{p_n l_n}{2} + \frac{\mu_n - \mu_{n-1}}{l_n}.$$

194. The moments of rupture upon the supports depend upon the circumstances in which the other bays are placed, and are calculated by Clapeyron's formula, the demonstration of which is found in the works of MM. Bélanger and Bresse, and to which we can merely allude: it is the following relation connecting the moments of rupture $\mu_{n-1}$, $\mu_n$, $\mu_{n+1}$, upon three consecutive supports, Fig. 1790,

$$\mu_{n-1} l_n + 2\mu_n (l_n + l_{n+1}) + \mu_{n+1} l_{n+1} + \frac{1}{4}(p_n l_n^3 + p_{n+1} l_{n+1}^3) = 0.$$

Applying this relation to each group of two consecutive bays, we have $m - 1$ equations ($m$ being the number of bays in the bridge) between the $m - 1$ moments of rupture upon the piers, those upon the abutments being nul. These equations may be immediately written under a numerical form with the given bearings and loads, and the resolution effected; then the moments upon the supports being all known and represented by ordinates to a given scale, we have only to apply a parabolic model corresponding to each bay, keeping their axes vertical. We thus construct the geometrical locus of the moments of rupture over all the bridge, not only for a particular mode of loading, but for all which are capable of producing a maximum strain upon certain portions of the girder. For a determinate plan, two parabolic models are sufficient, one for the dead weight only, which is supposed to be constant throughout the bridge, at least when the length of the bays do not differ too much; and the other for the maximum total load, including the dead and the rolling weights.

The several loci thus traced cut each other in certain points, and we make use only of the envelope, that is, of the portions of the curves giving the maxima ordinates in absolute value. In calculations for bridges of several bays, the cases in which the load would affect only portions of a bay are not considered.

Clapeyron's formula is established on the hypothesis that the moment of inertia of the girder remains constant throughout the length. This condition is hardly ever fulfilled, because the thickness of the flanges is made to vary for the purpose of economizing material. Yet we generally regard calculations made on the hypothesis of a constant section as applying with sufficient approximation to a case in which the section varies. It is then prudent not to reduce too much the maximum thickness of the flanges, which, in the computation of weight, will amount to forcing a little the coefficient U.

195. In the particular case of two bays each equal to $l$, and loaded respectively with $p_1$ and $p_2$ a mètre, the moment of rupture upon the pier will be $-\frac{(p_1 + p_2) l^2}{16}$.

In the case of three bays, $l_1$, $l_2$, $l_3$, the respective loads of which are $p_1, p_2, p_3$, we have for the moments $\mu_1$ and $\mu_2$ upon the first and second pier

$$\mu_1 = -\frac{2p_1 l_1^3 (l_2 + l_3) + p_2 l_2^3 (l_2 + 2l_3) - p_3 l_2 l_3^3}{16\left[l_1 (l_2 + l_3) + l_2\left(\frac{3}{4} l_2 + l_3\right)\right]}, \text{ and } \mu_2 = -\frac{p_2 l_2^3 + p_3 l_3^3 - 4 l_2 \mu_1}{8 (l_2 + l_3)}.$$

In a bridge in which the bays are numerous, the load upon one of them has a considerable effect upon those which are contiguous to it, but very little upon the others. Thus we may, with sufficient approximation, study successively each bay by taking into account the two next and rejecting the others; the calculations will in this way be made similar to those for bridges of two bays.

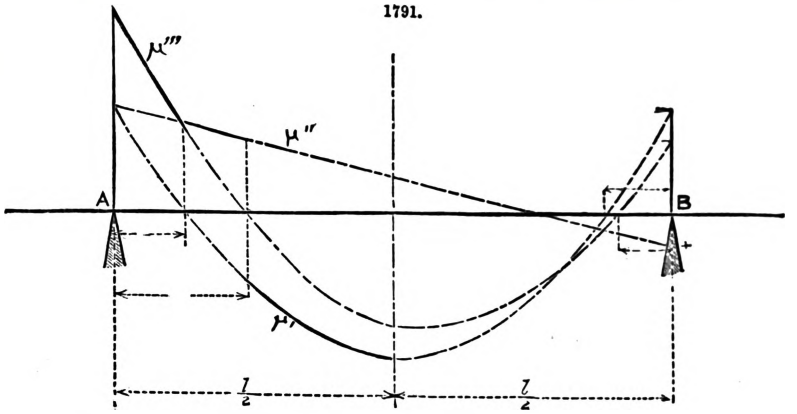
196. According to the remark made in section 84, the weight of the flanges of a girder is proportional to the mean ordinate G of the locus of the maximum moments of rupture in absolute value, and the vertical portion depends generally upon the mean ordinate G′ of the locus of the stress. We will, therefore, give the values of G and G′, applicable to bridges of several bays, and by the aid of which the computation of the weight of the girders may be effected without difficulty, as in the case of a single bay.

Let us consider, in the first place, a bridge of unlimited length, consisting of an infinite number of equal bays. Let $l$ be the length of each bay, $p$ the permanent load a mètre, and $p'$ the moving load.

The load $p$ will by itself produce, in a given bay, moments of rupture represented by the parabola $\mu = \frac{-p}{2}\left(\frac{l^2}{6} - lx + x^2\right)$; the supports ($x = 0$ and $x = l$) the moment is $\frac{-pl^2}{12}$, it is nul at the abscissa $0{\cdot}211\, l$, and takes with the contrary sign the value $\frac{pl^2}{24}$ in the middle of the bearing. This parabola is identical in form with that which we should have for a bridge of a single bay, but it is raised in such a manner that the segment which remains below the axis of the $x$'s is equivalent to the sum of the two segments situate above this axis, and having the from of triangles, one side of which is curvilineal. This circumstance, due to the continuity of the girder beyond the supports, affects only the flanges, the weight of which is diminished by it, but it has no influence whatever upon the vertical portion.

As to the load $p'$, if, in the first place, it be applied exclusively to the bay under consideration, A B, Fig. 1791, it will give upon the supports A and B moments of rupture equal to $-0{\cdot}0528\,p'\,l^2$,

1791.




which we carry above the axis of the $x$'s, and which will determine the position of the parabola of the parameter $\frac{1}{p'}$, having for equation $\mu' = \frac{p'x}{2}(l-x) - 0{\cdot}0528\,p'\,l^2$.

If now we apply the load $p'$, not upon A B, but only upon the contiguous bay to the left of A, the moment upon A will retain the same value, that in a line with the support B will take the value $+0{\cdot}0141\,p'\,l^2$, and a right line joining the summits of the ordinates to the supports, and having for equation $\mu'' = 0{\cdot}0669\,p'\,l\,x - 0{\cdot}0528\,p'\,l^2$, will represent the moments of rupture produced in the bay under consideration. If we consider again the case in which the bay A B and the preceding one are simultaneously loaded, to the exclusion of all the others, the moments upon A and B will be respectively $-0{\cdot}1056\,p'\,l^2$ and $-0{\cdot}0387\,p'\,l^2$, and the locus of the intermediate moments due to $p'$ will be the parabola $\mu''' = -\frac{p'x^2}{2} + 0{\cdot}5669\,p'\,l\,x - 0{\cdot}1056\,p'\,l^2$. The maximum moments in absolute value will be given by the portions of the curves traced in full lines upon the figure; that is, by $\mu'''$ between the limits $x = 0$ and $x = 0{\cdot}12\,l$, by $\mu''$ between $x = 0{\cdot}12\,l$ and $0{\cdot}235\,l$, and beyond as far as the middle by $\mu'$. Upon the other half of the bay the same branches of the curves may be symmetrically reproduced.

If we add the moment due to the dead weight $p$, as it changes its sign at the abscissa $0{\cdot}211\,l$, it will be in a point comprised between $x = 0{\cdot}211\,l$ and $x = 0{\cdot}235\,l$, values which differ but little, so that the resulting positive moment will begin to exceed the negative, and when $\mu''$ should be abandoned for $\mu'$.

The area comprised between the axis of the $x$'s and the locus of the absolute maximum moments is equal to $l^3(0{\cdot}0160\,p + 0{\cdot}0296\,p')$ for the half-bay, and dividing by $\frac{l}{2}$ we obtain the reduced ordinate $G = l^2(0{\cdot}032\,p + 0{\cdot}059\,p') = 0{\cdot}032\,(p+p')\,l^2(1 + 0{\cdot}844\,q)$.

The maximum stress corresponds throughout the bay to $\mu'''$, which gives by differentiation $F''' = \frac{d\mu'''}{dx} = -p'x + 0{\cdot}5669\,p'\,l$. Adding the stress due to the permanent load $p$, we find the value of the reduced ordinate of the limiting stress to be

$$G' = l\,(0{\cdot}25\,p + 0{\cdot}3169\,p') = 0{\cdot}25\,(p+p')\,l\,(1 + 0{\cdot}268\,q).$$

197. In the ordinary cases in which the mean weight of the lineal mètre of girder may be expressed by formulæ of the form $A\,G + B\,G' + C$, the values found above will be substituted for G and G', and for A, B, C, the quantities applicable to the system of girder adopted and determined as in bridges of a single bay.

But for simple approximative computations it may be more convenient to profit by the ready-found results which we have given for bridges of a single bay; and to do this, we must know the span of a single-bay bridge the mean weight of which per lineal mètre would be equivalent to that of the bridge of several bays under consideration.

Now, in the case of a single bay of a span $l'$, the mean ordinate of the limiting moments of rupture is $G_1 = \frac{1}{12}(p+p')\,l'^2$, and that of the stress $G'_1 = \frac{1}{4}(p+p')\,l'\left(1 + \frac{1}{6}q\right)$. Thus for the bridge of unlimited length considered in the preceding section, we may make, supposing that the term C, which is always small, remains constant,

$$0{\cdot}032\,A\,l^2(1 + 0{\cdot}844\,q) + 0{\cdot}25\,B\,l\,(1 + 0{\cdot}268\,q) = \frac{1}{12}A'\,l'^2 + \frac{1}{4}B'\,l'\left(1 + \frac{1}{6}q\right),$$

$$\text{or}\quad l'^2 + 3\left(1 + \frac{1}{6}q\right)\frac{B'}{A'}\,.\,l' - 0{\cdot}384\,(1 + 0{\cdot}844\,q)\,\frac{A\,l^2}{A'} - 3\,(1 + 0{\cdot}268\,q)\,\frac{B\,l}{A'} = 0,$$

an equation whence we may deduce the span $l'$ of the auxiliary bridge.

198. Suppose the case of multiple lattice-girders at 45°, stiffened by special vertical rods. We shall have $A = \frac{2\,U\,t}{\quad}$ and $B = B' = 2\,t$. If we take $h = \frac{l}{10}$ and $U = 1{\cdot}25$, and retain these values

for the auxiliary bridge, so that we have $A = A'$; and if we take $q = 0{\cdot}60$, a value which will be generally near enough, we shall obtain $l' = 0{\cdot}803\, l$. Thus, under these conditions, the weight a mètre of a bridge of numerous bays will be evidently the same as that of a single bay equal in length to $0{\cdot}8$ of one of the bays of the bridge under consideration, and having girders of the same height.

For example, if the bridge of unlimited length consists of bays of 40 mètres, we shall have $l' = 32$ mètres. Now, by interpolating in the Tables given for the case of one bay, we may estimate at 2300 kilogrammes the weight a mètre of a bridge of 32 mètres, composed of two girders of $3^{m}{\cdot}85$ high and placed beneath the rails, if we suppose the depth allowed unlimited (Table XII. E). As this height of $3{\cdot}85$ differs but little from that of 4 mètres, supposed by the preceding calculation, we may admit that the weight of 2300 kilogrammes a mètre of bearing is applicable to the unlimited bridge under consideration.

199. In a bridge of two bays each equal to $\iota$, if we go from one abutment taken as the beginning of the $x$'s, the maximum moment in absolute value will be first given by the hypothesis that the bay under consideration bears alone the full load $p + p'$ a mètre, whilst the second is reduced to the permanent load $p$. This moment is then expressed by the equation

$$\mu = \frac{1}{16}(6p + 7p')\, l x - \frac{1}{2}(p + p')\, x^2.$$

From $x = \frac{3}{4}\, l$, we must, on the contrary, load only the second bay, and we have the equation $\mu = \frac{1}{16}(-6p + p')\, l x + \frac{1}{2} p x^2$. And from $x = \frac{7}{8}\, l$ to $x = l$ we have, both bays being loaded, $\mu = \frac{1}{8}(p + p')(4x - 3l)\, x$. Squaring the area of the locus of the limiting moments and dividing the result by $l$, we obtain the reduced ordinate of the moments,

$$G = l^2 (0{\cdot}0495\, p + 0{\cdot}0702\, p') = 0{\cdot}0495\,(p + p')\, l^2 (1 + 0{\cdot}418.q).$$

For the stress, the reduced ordinate will be

$$G' = l\,(0{\cdot}2656\, p + 0{\cdot}2910\, p') = 0{\cdot}2656\,(p + p')\, l\,(1 + 0{\cdot}096.q).$$

With the hypotheses of the preceding section, we should find as the bearing of the auxiliary bridge of the same weight a mètre $l' = 0{\cdot}883\, l$, a value which should be increased to $0{\cdot}90\, l$ for example, because in a bridge of two bays we should increase G' if, instead of confining ourselves to hypotheses of complete loads for each bay, we considered besides loads extending over any portion of the girder. This consideration loses its importance as the number of the bays increases, because then the several hypothetical loads becoming more numerous offer more varied circumstances. In certain cases two independent bays of bow-girders may be more advantageous than two continuous bays of straight girders.

200. In a bridge of three equal bays, if $l$ is the length of bay, half the length of the bridge will be $L = \frac{3}{2}\, l$, and we shall have

$$G = L^2 (0{\cdot}0201\, p + 0{\cdot}0319\, p') = 0{\cdot}0201\,(p + p')\, L^2 (1 + 0{\cdot}589.q) = 0{\cdot}452\,(p + p')\, l^2 (1 + 0{\cdot}589.q);$$

and $$G' = 0{\cdot}1711\,(p + p')\, L\,(1 + 0{\cdot}188.q) = 0{\cdot}2567\,(p + p')\, l\,(1 + 0{\cdot}188.q).$$

With the same data as for the preceding cases, we find $l' = 0{\cdot}881.l$.

201. In a bridge of three bays, if we suppose the middle one equal to $\frac{5}{4}$ of one of the end ones, a small saving will be effected over the arrangement of three equal bays, for, L still denoting half the length of the bridge ($= 1{\cdot}625$ times an end bay), we shall have

$$G = L^2 (0{\cdot}0188\, p + 0{\cdot}0308\, p') \text{ and } G' = 0{\cdot}1749\,(p + p')\, L\,(1 + 0{\cdot}180.q).$$

202. For a bridge of four equal bays, $l$ being the length of one bay, we shall have

$$G = l^2 (0{\cdot}0415\, p + 0{\cdot}0693\, p') = 0{\cdot}0415\,(p + p')\, l^2 (1 + 0{\cdot}67.q);$$

and $$G' = l\,(0{\cdot}256\, p + 0{\cdot}31\, p') = 0{\cdot}256\,(p + p')\, l\,(1 + 0{\cdot}22.q).$$

with the data already adopted (198) for multiple lattice-girders, we should have here $l' = 0{\cdot}865\, l$.

203 *a*. For bridges of more than four bays, the weight a mètre will be the same as for a bridge of a single bay having a bearing between the values of $l'$ calculated for the case of four bays, and for that of an unlimited number of bays. For example, for five bays, with the same hypotheses as before, we might take $l' = 0{\cdot}85\, l$.

203 *B*. In computations which are required to be as exact as possible, the weight of the girders should be calculated directly by formulæ in which G and G' have the values given above according to the number of bays. In general, girders resting upon several supports will be either of multiple lattice or of crosses or cross-lattice. In the former case, we shall have as the mean weight of the mètre of girder without vertical rods,

$$\frac{P}{l} = \frac{2\,t\,U}{h}\, G + (1 + V)\, t\, G' + \frac{1}{2}(p + p')\, t\, h + \frac{60\, h^2}{l} + \Omega.$$

If there are vertical rods placed at a distance $\delta$ from each other, a term $\frac{15\, h^2}{\delta}$ must be added, supposing the sections of Fig. 1728 to be adopted.

For a girder of crosses or cross-lattice, without vertical rods, we shall have the following approximative formula, more general than those of sections 97 and 99·

$$\frac{P}{l} = \frac{2tU}{h} G + \frac{1}{2}(1+V)\left(\frac{Nh}{l} + \frac{}{Nh}\right) t G' + \frac{1}{4}(1+V)(p+p')th + \Omega,$$

N denoting the number of crosses in a bay $l$. If there are vertical rods, they must be taken into account by a term $\frac{rNh}{l}$ as in section 100, $r$ being the weight of the rod a mètre.

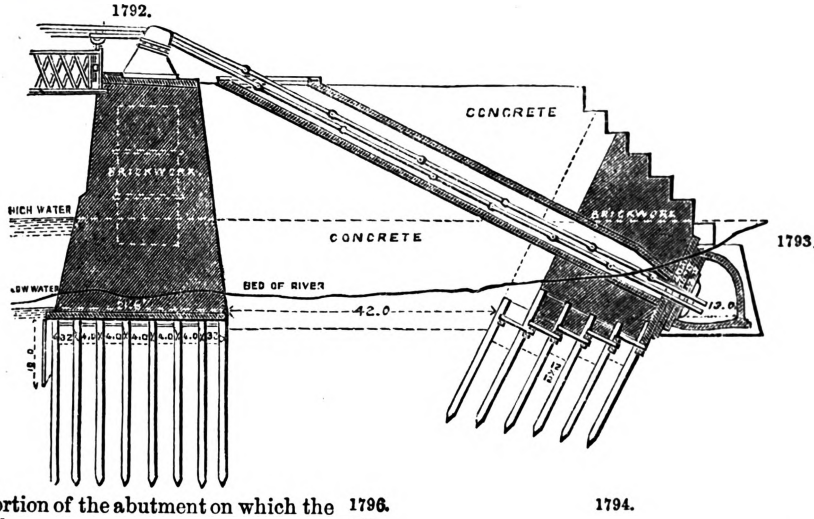
The continuity of the girders from one bay to another having the effect of lightening the flanges, whilst it tends to increase slightly the vertical portion, a less height should be adopted than in bridges of a single bay. In general the ratio of the height of the girders to the length of a bay will not exceed $\frac{1}{10}$.

Figs. 1792 to 1801 are of the principal details of the Chelsea Suspension Bridge.

The abutments of this bridge consist of a mass of brickwork and concrete, measuring at the base 112 ft. in length by 56 ft. broad, and at the top 100 ft. by 46 ft., and 40 ft. deep.

The face of the abutment adjoining the river is composed of cast-iron piles and plates, somewhat similar to those of the pier, with the exception that the ironwork is not brought above the level of low water.

1792.



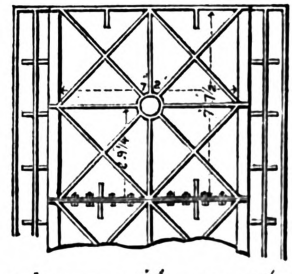

The portion of the abutment on which the land saddles and cradles bear, for changing the direction of the chains, rests upon timber piles, 14 in. square, driven deep into the bed of the river, and are from 3 ft. 2 in. to 4 ft. from centre to centre: these piles are cut off at the level of low water, 16 ft. below Trinity high-water mark, and the spaces between filled up with hydraulic concrete; the cast-iron and timber piles are tied together with wrought-iron ties 3 in. × $\frac{3}{4}$ in. On the top is bedded a series of landings forming a table at the level of low water 53 ft. 6 in. × 27 ft. × 6 in., upon which a mass of brickwork is erected, up to a mean level of 3 ft. below the level of the roadway; upon this, 12 in. landings are bedded for the reception of the cradles which carry the saddles on rollers: the cradles are bedded in asphalted felt, and firmly secured by wrought-iron holding-down bolts, brought up through the masonry from below. An invert, springing from beneath each saddle, is built in the brickwork below, so as to distribute equally the pressure from the cradles over the whole area of the foundation.

The mooring chains are carried down tunnels to the moorings, the tunnels forming an angle of 155° with a horizontal line. The chains are secured to massive cast-iron mooring plates, resting against three courses of 12 in. landings, respectively 12 ft. × 8 ft. 9 in., 16 ft. × 12 ft. 6 in., and 20 ft. × 16 ft. 3 in. The tunnels are contracted at the bottom by elliptical brick domes, thus afford-

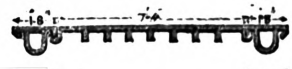
1796.

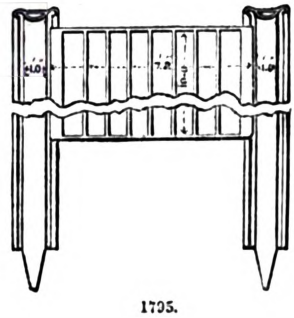
1797.

1794.



1798.





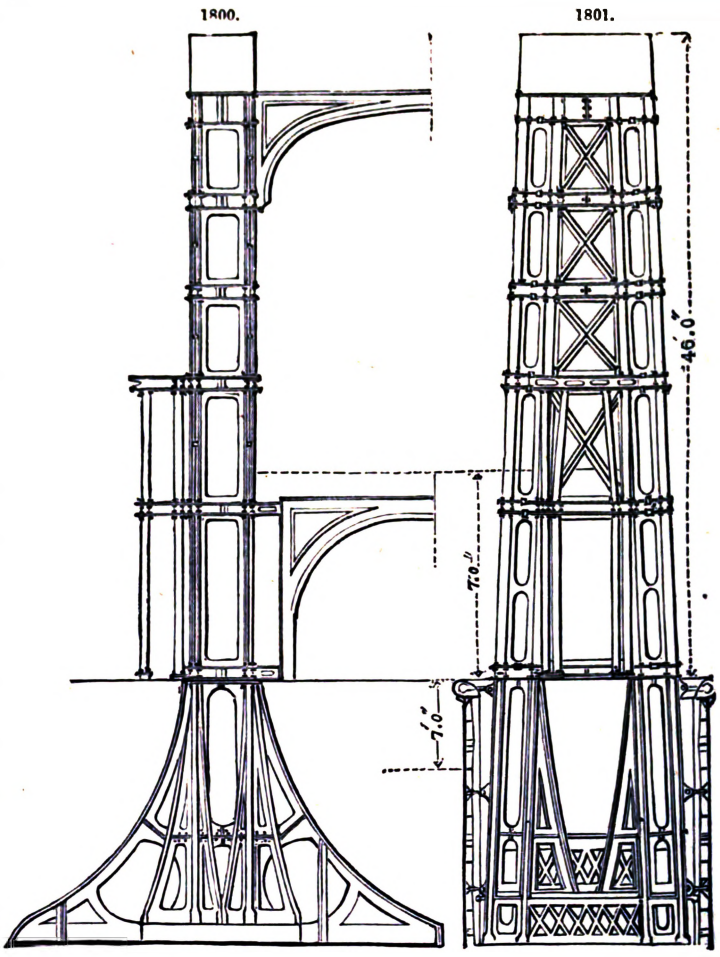
1795.

1799.

ing a complete bearing for that portion of the landings at the end of the tunnel. These landings rest against a mass of brickwork, with inverts, to distribute the pressure over the whole area of the abutment.

This mass of brickwork rests on a series of timber piles, driven at an angle of 65° with a horizontal line; the tops of the piles coming up above the level of the concrete, and having a good bond with the brickwork, by which means the tendency to slide is greatly diminished, the whole spaces between the masses of brickwork being filled up solid with concrete.

*The Pier Foundations*, Figs. 1792, 1793.—The construction of the foundations of the piers combines all the advantages of foundations on bearing-piles, made by means of cofferdams, without the expense and obstruction to the waterway which they involve, and which would have rendered their use at Westminster Bridge all but impracticable.




The foundations of the piers consist of timber bearing-piles 14 in. square, driven deep into the bed of the river at intervals of 3 ft. over the whole area of the pier, varying in depth from 40 ft. 6 in. to 25 ft. below the level of low water, according to the resistance offered by the bed of the river.

The face or external surface of the piers consists of a cast-iron casing of piles and plates driven alternately; the main piles are 12 in. in diameter and 27 ft. long, with longitudinal grooves on each side for the reception of the plates. These piles are driven to a uniform depth of 25 ft. below the level of low water, and between them are driven cast-iron plates or sheeting 7 ft. 2 in. wide, so that the pier is entirely cased from the foundations to the top, which is 7 ft. 6 in. above Trinity datum. The space enclosed by this casing is then dredged to the hard gravel above the clay, and filled in solid with concrete up to the level of the top of the timber piles. On this foundation a flooring of stone landings is bedded, and on this the cast-iron plates, frames, &c., forming the base of the towers, are placed.

The portion of the caisson situated above low water is hollow, being so formed to avoid throwing useless weight on the foundation, and is merely lined with brickwork, strengthened by cross-walls and iron ties.

The whole of the ironwork below the water was covered when hot with a protecting coating of tar. The thickness of metal in the caisson is 1 in.

The towers, Figs. 1800, 1801, which support the chains are entirely independent of the ornamental cast-iron casing surrounding them, and consist of a cast-iron columnar framing strongly braced both horizontally and vertically, carried to a height of 57 ft. above high water.

The columns are cast in pairs and have a diameter of 10 in., and thickness of metal of 1 in. They are arranged in clusters of fours, and the whole are connected with six horizontal frames, occurring at intervals. The columns are not vertical, but incline towards each other upwards from either side of the pier, the columnar framing being 13 ft. 6 in. at the base, and 9 ft. 9 in. at the top. In the direction of the piers the columns are 4 ft. 3 in. apart, and rise parallel to each other. There are two towers on each pier, 32 ft. from centre to centre. The pressure from the chains coming directly from their centre, each tower carries therefore one-fourth of the whole weight of the bridge, or about 375 tons, or about 670 tons when the bridge is completely loaded; the sectional area of the columns is 284 sq. in., and there is, therefore, a pressure upon them, when the bridge is loaded, of 2·36 tons per sq. in. of section. The weight of the towers, exclusive of the ornamental cast-iron casing, is 350 tons.

On the towers are fixed massive cast-iron cradles upon which the saddles rest.

| Case in which $\alpha = \beta = 45°$. | Case in which $\beta = 90°$. | Case in which $\alpha = 90°$. |
|---|---|---|
| $h\sqrt{2}\left[(2n-1)p + \frac{(m+n)(m+n-1)}{2m}p'\right]$ | $\frac{\delta\sqrt{h^2+\delta^2}}{2h}\left[(2n-1)p + \frac{(m+n)(m+n-1)}{2m}p'\right]$ | $\frac{\delta}{2}\left[(2n-1)p + \frac{(m+n)(m+n-1)}{2m}p'\right]$ |
| — | $\frac{\delta}{2}\left[(2n-1)p + \frac{(m+n)(m+n-1)}{2m}p'\right]$ | $\frac{\delta\sqrt{h^2+\delta^2}}{2h}\left[(2n-1)p + \frac{(m+n)(m+n-1)}{2m}p'\right]$ |
| $2(m-n+1)(m+n-1)(p+p')h$ | $(m-n+1)(m+n-1)(p+p')\frac{\delta^2}{2h}$ | $(m-n+1)(m+n-1)(p+p')\frac{\delta^2}{2h}$ |
| $2\left(m-n+\frac{1}{2}\right)\left(m+n-\frac{1}{2}\right)(p+p')h$ | — | $(m^2-n^2)(p+p')\frac{\delta^2}{2h}$ |
| $(p+p')\frac{l^2}{8h}$ | $(p+p')\frac{l^2}{8h}$ | $(p+p')\frac{l^2}{8h}$ |
| $(2m^2-1)(p+p')h$ | — | $(m^2-1)(p+p')\frac{\delta^2}{2h}$ |
| $2h^2tV\left(2m^2p + \frac{7m^2-1}{3}p'\right)$ | $\frac{\delta(h^2+\delta^2)tV}{h}\left(m^2p + \frac{7m^2-1}{6}p'\right)$ | $\delta h tV\left(m^2p + \frac{7m^2-1}{6}p'\right)$ |
| $2h^2t\left(2m^2p + \frac{7m^2-1}{3}p'\right)$ | $\delta h t\left(m^2p + \frac{7m^2-1}{6}p'\right)$ | $\frac{\delta(h^2+\delta^2)t}{h}\left(m^2p + \frac{7m^2-1}{6}p'\right)$ |
| $4m(4m^2-1)(p+p')\frac{h^2tU}{3}$ | $m(4m+1)(m-1)(p+p')\frac{\delta^3tU}{6h}$ | $m(4m-1)(m+1)(p+p')\frac{\delta^3tU}{6h}$ |
| — | $m(4m-1)(m+1)(p+p')\frac{\delta^3tU}{6h}$ | $m(4m+1)(m-1)(p+p')\frac{\delta^3tU}{6h}$ |
| $\frac{8m}{3}(4m^2-1)(p+p')h^2tU$ | $m(4m^2-1)(p+p')\frac{\delta^3tU}{3h}$ | $m(4m^2-1)(p+p')\frac{\delta^3tU}{3h}$ |
| $h\sqrt{2}\left[2np + \frac{(m+n)(m+n+1)}{2m+}p'\right]$ | $\frac{\delta\sqrt{h^2+\delta^2}}{h}\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)}p'\right]$ | $\delta\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)}p'\right]$ |
| — | $\delta\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)}p'\right]$ | $\frac{\delta\sqrt{h^2+\delta^2}}{h}\left[np + \frac{(m+n)(m+n+1)}{2(2m+1)}p'\right]$ |
| $2(m+n)(m-n+1)(p+p')h$ | $(m+n)(m-n+1)(p+p')\frac{\delta^2}{2h}$ | $(m+n)(m-n+1)(p+p')\frac{\delta^2}{2h}$ |

TRIANGULAR LATTICE-GIRDERS LOADED ON THE LOWER SIDE—*continued.*

| Case in which $\alpha = \beta = 45^\circ$. | Case in which $\beta = 90^\circ$. | Case in which $\alpha = 90^\circ$. |
|---|---|---|
| $2\,(m^2 - n^2 + m + 2n - 1)\,(p + p')\,h$ | $(m^2 - n^2 + m + 3n - 2)\,(p + p')\,\frac{\delta^2}{2h}$ | $(m + n)\,(m - n + 1)\,(p + p')\,\frac{\delta^2}{2h}$ |
| $2m\,(m + 1)\,(p + p')\,h$ | $m\,(m + 1)\,(p + p')\,\frac{\delta^2}{2h}$ | $m\,(m + 1)\,(p + p')\,\frac{\delta^2}{2h}$ |
| $4m\,(m + 1)\,h^2\,t\,V\left(p + \frac{7}{6}\,p'\right)$ | $\frac{m\,(m + 1)\,\delta\,(h^2 + \delta^2)\,t\,V}{h}\left(p + \frac{7}{6}\,p'\right)$ | $m\,(m + 1)\,\delta\,h\,t\,V\left(p + \frac{7}{6}\,p'\right)$ |
| $4m\,(m + 1)\,h^2\,t\left(p + \frac{7}{6}\,p'\right)$ | $m\,(m + 1)\,\delta\,h\,t\left(p + \frac{7}{6}\,p'\right)$ | $\frac{m\,(m + 1)\,\delta\,(h^2 + \delta^2)\,t}{h}\left(p + \frac{7}{6}\,p'\right)$ |
| $\frac{8}{3}\,m\,(m + 1)\,(2m + 1)\,(p + p')\,h^2\,t\,U$ | $m\,(4m - 1)\,(m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{6h}$ | $m\,(4m + 5)\,(m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{6h}$ |
| ——— | $m\,(4m + 5)\,(m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{6h}$ | $m\,(4m - 1)\,(m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{6h}$ |
| $\frac{16m}{3}\,(m + 1)\,(2m + 1)\,(p + p')\,h^2\,t\,U$ | $\frac{2}{3}\,m\,(m + 1)\,(2m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{h}$ | $\frac{2}{3}\,m\,(m + 1)\,(2m + 1)\,(p + p')\,\frac{\delta^3\,t\,U}{h}$ |

MOMENTS OF RESISTANCE (13). TABLE I.—DOUBLE I IRON.

| Height. | Breadth of the Flanges. | Thickness | | Moment of Resistance for R = 6000000. | Weight the Lineal Mètre. | Height. | Breadth of the Flanges. | Thickness | | Moment of Resistance for R = 6000000. | Weight the Lineal Mètre. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Of the Vertical Rib. | Of the Flanges. | | | | | Of the Vertical Rib. | Of the Flanges. | | |
| mill. | mill. | mill. | mill. | | kilos. | mill. | mill. | mill. | mill. | | kilos. |
| 100 | 43 | 5 | 6 | 171 | 9 | 180 | 55 | 8 | 9 | 671 | 20 |
| ,, | 48 | 10 | 6 | 220 | 13 | ,, | 63 | 16 | 9 | 930 | 31·5 |
| 120 | 45 | 5 | 6 | 228 | 11 | ,, | 120 | 10 | 12 | 1568 | 37 |
| ,, | 52 | 12 | 7 | 352 | 17·5 | 200 | 65 | 8 | 10 | 938 | 22 |
| ,, | 65 | 6·5 | 9 | 418 | 15 | ,, | 73 | 16 | 10 | 1257 | 35 |
| 140 | 47 | 6 | 7 | 335 | 14 | ,, | 110 | 10 | 12 | 1674 | 37·4 |
| ,, | 51 | 10 | 7 | 413 | 18·5 | 220 | 64 | 8 | 10 | 1060 | 26 |
| ,, | 76 | 8 | 10 | 650 | 30 | ,, | 72 | 16 | 10 | 1448 | 40 |
| 160 | 48 | 8 | 7 | 450 | 15 | 260 | 120 | 10 | 12 | 2550 | 45 |
| ,, | 55 | 15 | 8 | 661 | 24 | 300 | 120 | 12 | 14 | 3555 | 55 |
| ,, | 80 | 8 | 10 | 813 | 22·2 | | | | | | |

TABLE II.—DOUBLE-FLANGED WROUGHT-IRON GIRDERS WITH ANGLE-IRON.

| Height. | Vertical Rib. | Four Angle-irons of | Two Flanges of | Moment of Resistance for R = 6000000. | Weight the Lineal Mètre. | Height. | Vertical Rib. | Four Angle-irons of | Two Flanges of | Moment of Resistance for R = 6000000. | Weight the Lineal Mètre. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m. | mill. | mill. | mill. | | kilos. | m. | mill. | mill. | mill. | | kilos. |
| 0·200 | 200/6 | 60/60/9 | .. | 1890 | 40 | 0·350 | 290/10 | 100/100/12 | 300/30 | 20964 | 234 |
| ,, | 200/6 | 70/70/10 | .. | 2320 | 50 | | | | | | |
| ,, | 200/10 | 70/70/10 | .. | 2478 | 56 | 0·400 | 400/6 | 70/70/10 | .. | 6020 | 50 |
| ,, | 200/8 | 80/80/10 | .. | 2630 | 60 | ,, | 400/6 | 80/80/10 | .. | 6663 | 66 |
| ,, | 200/8 | 80/80/11 | .. | 2820 | 64 | ,, | 400/8 | 110/70/10 | .. | 8165 | 78 |
| ,, | 200/10 | 110/70/10 | .. | 3146 | 69 | ,, | 400/10 | 100/100/12 | .. | 9730 | 102 |
| ,, | 200/10 | 110/70/11 | .. | 3593 | 74 | ,, | 400/10 | 100/65/14 | .. | 10085 | 97 |
| ,, | 180/6 | 70/70/10 | 160/10 | 3528 | 74 | ,, | 380/10 | 70/70/10 | 200/10 | 10453 | 102 |
| ,, | 180/10 | 70/70/10 | 200/10 | 4078 | 86 | ,, | 380/10 | 80/80/10 | 200/10 | 11022 | 107 |
| ,, | 180/10 | 110/70/11 | 230/10 | 5288 | 108 | ,, | 380/10 | 70/70/10 | 250/10 | 11594 | 109 |
| ,, | 160/10 | 100/70/10 | 250/20 | 6710 | 135 | ,, | 380/10 | 80/80/10 | 300/10 | 13305 | 123 |
| 0·220 | 200/8 | 60/60/10 | 150/10 | 3763 | 70 | ,, | 380/10 | 100/100/12 | 250/10 | 14311 | 139 |
| ,, | 160/12 | 110/70/11 | 300/30 | 10888 | 210 | ,, | 380/10 | 100/100/12 | 300/10 | 15452 | 147 |
| | | | | | | ,, | 360/10 | 80/80/10 | 250/20 | 16512 | 153 |
| 0·250 | 250/6 | 60/60/10 | .. | 2830 | 46 | ,, | 360/10 | 100/100/12 | 250/20 | 18398 | 177 |
| ,, | 250/6 | 70/70/10 | .. | 3175 | 52 | ,, | 360/10 | 80/80/10 | 300/20 | 18680 | 169 |
| ,, | 250/6 | 80/80/10 | .. | 3500 | 59 | ,, | 340/10 | 80/80/10 | 250/30 | 20378 | 190 |
| ,, | 250/10 | 110/70/11 | .. | 4870 | 78 | ,, | 360/10 | 100/100/12 | 300/20 | 20566 | 192 |
| ,, | 230/8 | 70/70/10 | 200/10 | 5455 | 86 | ,, | 340/10 | 100/100/12 | 250/30 | 22021 | 214 |
| ,, | 230/10 | 80/80/10 | 200/10 | 5826 | 96 | ,, | 360/10 | 100/100/12 | 350/20 | 22734 | 208 |
| ,, | 210/10 | 70/70/10 | 150/20 | 6055 | 104 | ,, | 340/10 | 80/80/10 | 300/30 | 23460 | 214 |
| ,, | 230/10 | 70/70/10 | 200/30 | 8754 | 149 | ,, | 340/10 | 100/100/12 | 300/30 | 25108 | 237 |
| ,, | 250/10 | 140/70/16 | .. | 7677 | 116 | ,, | 340/10 | 100/100/12 | 350/30 | 28195 | 261 |
| ,, | 210/10 | 110/70/11 | 300/20 | 10864 | 168 | | | | | | |
| ,, | 190/10 | 110/70/11 | 300/30 | 13063 | 213 | 0·450 | 450/6 | 70/70/10 | .. | 7039 | 62 |
| | | | | | | ,, | 450/6 | 80/80/10 | .. | 7795 | 68 |
| 0·300 | 300/6 | 70/70/7 | .. | 3126 | 43 | ,, | 450/10 | 80/80/10 | .. | 8605 | 82 |
| ,, | 300/6 | 60/60/9 | .. | 3365 | 45 | ,, | 450/10 | 110/70/10 | .. | 9125 | 88 |
| ,, | 300/6 | 60/60/10 | .. | 3630 | 48 | ,, | 450/10 | 100/100/12 | .. | 11455 | 106 |
| ,, | 300/6 | 70/70/10 | .. | 4036 | 55 | ,, | 430/10 | 70/70/10 | 200/10 | 12198 | 105 |
| ,, | 300/6 | 80/80/10 | .. | 4513 | 61 | ,, | 430/10 | 80/80/10 | 200/10 | 12882 | 112 |
| ,, | 300/6 | 110/70/11 | .. | 5860 | 72 | ,, | 430/10 | 80/80/10 | 300/10 | 15464 | 127 |
| ,, | 300/6 | 100/100/12 | .. | 6125 | 85 | ,, | 430/10 | 100/100/12 | 250/10 | 16734 | 143 |
| ,, | 280/10 | 70/70/10 | 150/10 | 6282 | 86 | ,, | 430/10 | 100/100/12 | 350/10 | 19316 | 159 |
| ,, | 280/10 | 70/70/10 | 250/10 | 7970 | 102 | ,, | 390/10 | 70/70/10 | 200/30 | 19704 | 175 |
| ,, | 280/10 | 80/80/10 | 250/10 | 8328 | 108 | ,, | 390/10 | 80/80/10 | 250/30 | 23778 | 194 |
| ,, | 280/10 | 80/80/10 | 300/10 | 9170 | 115 | ,, | 390/10 | 80/80/10 | 300/30 | 27312 | 218 |
| ,, | 260/10 | 80/80/10 | 200/20 | 9724 | 130 | ,, | 390/10 | 100/100/15 | 350/30 | 34338 | 281 |
| ,, | 280/10 | 100/100/12 | 300/10 | 10530 | 140 | | | | | | |
| ,, | 260/10 | 80/80/10 | 250/20 | 11295 | 145 | 0·480 | 480/8 | 80/80/10 | .. | 8952 | 77 |
| ,, | 240/10 | 70/70/10 | 200/30 | 11370 | 153 | 0·500 | 500/6 | 70/70/8 | .. | 6889 | 57 |
| ,, | 260/10 | 80/80/10 | 300/20 | 12866 | 161 | ,, | 500/6 | 70/70/10 | .. | 8088 | 64 |
| ,, | 260/10 | 100/100/12 | 300/20 | 14000 | 185 | ,, | 500/8 | 70/70/10 | .. | 8592 | 72 |
| ,, | 240/10 | 80/80/10 | 300/30 | 16006 | 206 | ,, | 500/10 | 80/80/10 | .. | 9962 | 86 |
| | | | | | | ,, | 500/10 | 110/70/10 | .. | 11397 | 92 |
| 0·330 | 330/8 | 90/90/11 | .. | 6258 | 79 | ,, | 500/10 | 100/100/12 | .. | 13240 | 110 |
| 0·350 | 350/6 | 50/50/7 | .. | 3240 | 36 | ,, | 480/10 | 70/70/10 | 200/10 | 14004 | 109 |
| ,, | 350/6 | 60/60/10 | .. | 4470 | 51 | ,, | 480/10 | 80/80/10 | 200/10 | 14800 | 115 |
| ,, | 350/6 | 70/70/8 | .. | 4261 | 50 | ,, | 480/8 | 80/80/10 | 250/10 | 15798 | 116 |
| ,, | 350/6 | 70/70/10 | .. | 5034 | 57 | ,, | 480/8 | 80/80/10 | 300/10 | 17681 | 131 |
| ,, | 350/6 | 80/80/10 | .. | 5568 | 63 | ,, | 480/8 | 100/100/12 | 250/10 | 19222 | 140 |
| ,, | 350/6 | 110/70/10 | .. | 6618 | 70 | ,, | 480/8 | 100/100/12 | 300/10 | 20663 | 147 |
| ,, | 330/10 | 70/70/10 | 150/10 | 7764 | 90 | ,, | 460/10 | 80/80/10 | 250/20 | 21995 | 161 |
| ,, | 350/10 | 100/100/12 | .. | 8071 | 98 | ,, | 480/8 | 100/100/12 | 350/10 | 22104 | 155 |
| ,, | 330/10 | 70/70/10 | 200/10 | 8760 | 98 | ,, | 440/10 | 70/70/10 | 200/30 | 22620 | 168 |
| ,, | 330/10 | 80/80/10 | 200/10 | 9222 | 104 | ,, | 460/10 | 100/100/12 | 250/20 | 24695 | 185 |
| ,, | 330/10 | 80/80/10 | 300/10 | 11205 | 119 | ,, | 460/10 | 80/80/10 | 300/20 | 24761 | 176 |
| ,, | 320/6 | 70/70/10 | 250/15 | 11298 | 114 | ,, | 440/10 | 80/80/10 | 250/20 | 27248 | 198 |
| ,, | 310/8 | 70/70/10 | 250/20 | 12743 | 138 | ,, | 460/10 | 100/100/12 | 300/20 | 27461 | 200 |
| ,, | 330/10 | 100/100/12 | 300/10 | 12950 | 143 | ,, | 460/10 | 100/100/12 | 350/20 | 30228 | 216 |
| ,, | 310/10 | 80/80/10 | 250/20 | 13867 | 149 | ,, | 440/10 | 80/80/10 | 300/30 | 31229 | 222 |
| ,, | 310/8 | 100/100/12 | 250/20 | 15365 | 168 | ,, | 440/10 | 100/100/12 | 300/30 | 33662 | 245 |
| ,, | 310/8 | 70/70/10 | 300/20 | 15716 | 154 | ,, | 420/10 | 100/100/12 | 250/40 | 34203 | 259 |
| ,, | 310/8 | 100/100/12 | 300/20 | 17234 | 183 | ,, | 440/10 | 100/100/12 | 350/30 | 37644 | 268 |
| ,, | 310/8 | 100/100/12 | 350/20 | 19103 | 199 | ,, | 440/10 | 100/100/15 | 350/30 | 39372 | 285 |
| ,, | 290/10 | 80/80/10 | 300/30 | 19692 | 210 | ,, | 440/10 | 100/100/15 | 400/30 | 43363 | 308 |

TABLE II.—DOUBLE-FLANGED WROUGHT-IRON GIRDERS WITH ANGLE-IRON—*continued.*

| Height. | Vertical Rib. | Four Angle-irons of | Two Flanges of | Moment of Resistance for R = 6000000 | Weigh the Lineal Mètre. | Height. | Vertical Rib. | Four Angle-irons of | Two Flanges of | Moment of Resistance for R = 6000000 | Weight the Lineal Mètre. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m. | mill. | mill. | mill. | | kilos. | m | mill | mill | mill | | kilos. |
| 0·500 | 420/10 | 100/100/12 | 350/40 | 44385 | 322 | 0 800 | 740/10 | 70/70/10 | 200/30 | 41286 | 192 |
| | | | | | | | 780/10 | 100/100/15 | 400/10 | 46326 | 210 |
| 0·550 | 550/6 | 70/70/10 | .. | 9174 | 66 | ,, | 740/10 | 80/80/10 | 250/30 | 49278 | 226 |
| ,, | 550/8 | 80/80/10 | .. | 10764 | 81 | ,, | 740/10 | 80/80/10 | 300/30 | 55956 | 245 |
| ,, | 530/10 | 70/70/10 | 200/10 | 15858 | 113 | ,, | 740/10 | 100/100/15 | 400/30 | 77796 | 332 |
| ,, | 490/10 | 70/70/10 | 200/30 | 25590 | 172 | ,, | | | | | |
| ,, | 530/10 | 80/80/10 | 250/10 | 18360 | 127 | 0·850 | 850/8 | 70/70/10 | .. | 17784 | 94 |
| ,, | 490/10 | 80/80/10 | 250/30 | 30774 | 202 | ,, | 850/8 | 80/80/10 | .. | 19470 | 100 |
| ,, | 490/10 | 80/80/10 | 300/30 | 35202 | 225 | ,, | 830/10 | 70/70/10 | 200/10 | 28104 | 137 |
| ,, | 490/10 | 80/80/10 | 350/10 | 27378 | 183 | ,, | 830/10 | 80/80/10 | 250/10 | 33000 | 151 |
| ,, | 530/10 | 100/100/15 | 350/10 | 27378 | 183 | ,, | 830/10 | 80/80/10 | 300/10 | 34692 | 158 |
| ,, | 490/10 | 100/100/15 | 400/30 | 48936 | 312 | ,, | 830/10 | 100/100/15 | 400/10 | 49962 | 214 |
| 0·600 | 600/6 | 70/70/10 | .. | 10296 | 69 | ,, | 790/10 | 80/80/10 | 250/30 | 53142 | 225 |
| ,, | 600/6 | 80/80/10 | .. | 11393 | 75 | ,, | 790/10 | 100/100/15 | 400/30 | 83742 | 335 |
| ,, | 600/6 | 90/90/10 | .. | 12460 | 81 | ,, | | | | | |
| ,, | 600/10 | 80/80/10 | .. | 12834 | 94 | 0·900 | 900/8 | 70/70/10 | .. | 19260 | 97 |
| ,, | 600/10 | 100/100/12 | .. | 16983 | 117 | ,, | 900/8 | 80/80/10 | .. | 21066 | 103 |
| ,, | 580/6 | 80/80/10 | 200/10 | 17497 | 105 | ,, | 880/10 | 70/70/10 | 200/10 | 30324 | 140 |
| ,, | 580/10 | 70/70/10 | 200/10 | 17778 | 117 | ,, | 880/10 | 80/80/10 | 250/10 | 34686 | 154 |
| ,, | 580/10 | 80/80/10 | 250/10 | 20538 | 131 | ,, | 880/10 | 80/80/10 | 300/10 | 37326 | 162 |
| ,, | 580/10 | 80/80/10 | 300/10 | 22279 | 139 | ,, | 840/10 | 70/70/10 | 200/30 | 47934 | 200 |
| ,, | 580/10 | 100/100/12 | 250/10 | 24380 | 155 | ,, | 880/10 | 100/100/15 | 400/10 | 53646 | 218 |
| ,, | 580/10 | 100/100/12 | 350/10 | 27861 | 170 | ,, | 840/10 | 100/100/15 | 400/30 | 89748 | 340 |
| ,, | 540/10 | 70/70/10 | 200/30 | 28620 | 176 | 0 950 | 950/8 | 70/70/10 | .. | 20778 | 100 |
| ,, | 580/10 | 100/100/15 | 350/10 | 30588 | 187 | | 950/0 | 80/80/10 | .. | 22704 | 106 |
| ,, | 540/10 | 80/80/10 | 250/30 | 34368 | 206 | ,, | 930/10 | 70/70/10 | 200/10 | 32592 | 144 |
| ,, | 540/10 | 80/80/10 | 300/30 | 39246 | 229 | ,, | 890/10 | 70/70/10 | 200/30 | 51330 | 204 |
| ,, | 540/10 | 100/100/15 | 350/30 | 49704 | 293 | ,, | 930/10 | 100/100/15 | 400/10 | 57390 | 222 |
| ,, | 540/10 | 100/100/15 | 400/30 | 54582 | 316 | ,, | 890/10 | 100/100/15 | 400/30 | 95808 | 343 |
| 0·650 | 650/8 | 70/70/10 | .. | 12282 | 81 | ,, | | | | | |
| ,, | 650/6 | 80/80/10 | .. | 12659 | 78 | 1·000 | 1000/8 | 70/70/10 | .. | 22338 | 103 |
| ,, | 650/10 | 80/80/10 | .. | 14348 | 98 | ,, | 1000/8 | 80/80/10 | .. | 26382 | 125 |
| ,, | 650/10 | 100/100/12 | .. | 18937 | 121 | ,, | 1000/7 | 100/100/12 | .. | 31082 | 125 |
| ,, | 630/10 | 70/70/10 | 200/10 | 19740 | 121 | ,, | 980/10 | 70/70/10 | 200/10 | 34914 | 148 |
| ,, | 630/10 | 80/80/10 | 250/10 | 22764 | 135 | ,, | 980/10 | 80/80/10 | 250/10 | 39810 | 162 |
| ,, | 630/10 | 80/80/10 | 300/10 | 24654 | 143 | ,, | 980/10 | 80/80/10 | 300/10 | 42750 | 170 |
| ,, | 590/10 | 70/70/10 | 200/30 | 31704 | 180 | ,, | 940/10 | 70/70/10 | 200/30 | 54786 | 208 |
| ,, | 630/10 | 100/100/15 | 350/10 | 33858 | 190 | ,, | 940/10 | 100/100/15 | 400/30 | 101922 | 347 |
| ,, | 590/10 | 80/80/10 | 300/30 | 43338 | 233 | 1·100 | 1080/10 | 80/80/10 | 300/10 | 48384 | 178 |
| ,, | 590/10 | 100/100/15 | 400/30 | 60294 | 320 | ,, | 1080/10 | 100/100/15 | 350/10 | 65676 | 226 |
| 0 700 | 700/8 | 70/70/10 | .. | 13584 | 84 | ,, | 1040/10 | 100/100/15 | 400/30 | 114312 | 355 |
| ,, | 700/8 | 80/80/10 | .. | 14934 | 90 | 1·200 | 1200/10 | 100/100/12 | .. | 43854 | 164 |
| ,, | 680/10 | 70/70/10 | 200/10 | 21756 | 125 | ,, | 1180/10 | 100/100/12 | 300/10 | 64860 | 210 |
| ,, | 700/10 | 100/100/12 | .. | 21924 | 125 | ,, | 1180/10 | 100/100/15 | 400/10 | 76866 | 241 |
| ,, | 680/10 | 80/80/10 | 250/10 | 25044 | 139 | ,, | 1140/10 | 100/100/15 | 400/30 | 126906 | 363 |
| ,, | 680/10 | 80/80/10 | 300/10 | 27084 | 147 | 1·250 | 1230/10 | 80/80/10 | 300/10 | 57204 | 190 |
| ,, | 680/10 | 100/100/15 | 400/10 | 39216 | 202 | | 1230/10 | 100/100/15 | 350/10 | 77220 | 237 |
| ,, | 640/10 | 80/80/10 | 300/30 | 47478 | 237 | ,, | 1230/10 | 100/100/15 | 400/10 | 80910 | 245 |
| ,, | 640/10 | 100/100/15 | 400/30 | 66072 | 324 | ,, | 1190/10 | 100/100/15 | 400/30 | 133284 | 367 |
| 0 750 | 750/8 | 70/70/10 | .. | 14952 | 88 | 1·300 | 1300/10 | 100/100/12 | .. | 49059 | 172 |
| ,, | 750/8 | 80/80/10 | .. | 16404 | 94 | ,, | 1280/10 | 100/100/12 | 300/10 | 72460 | 219 |
| ,, | 730/10 | 70/70/10 | 200/10 | 23820 | 129 | ,, | 1280/10 | 100/100/15 | 350/10 | 81168 | 241 |
| ,, | 730/10 | 80/80/10 | 250/10 | 27378 | 143 | ,, | 1280/10 | 100/100/15 | 400/10 | 85008 | 249 |
| ,, | 730/10 | 80/80/10 | 300/10 | 29568 | 150 | ,, | 1180/10 | 100/100/12 | 300/60 | 189460 | 452 |
| ,, | 690/10 | 70/70/10 | 200/30 | 38040 | 188 | 1·400 | 1380/10 | 100/100/12 | 300/10 | 79660 | 226 |
| ,, | 730/10 | 100/100/15 | 400/10 | 42744 | 206 | ,, | 1380/10 | 80/80/10 | 300/10 | 66480 | 201 |
| ,, | 690/10 | 80/80/10 | 250/30 | 45468 | 218 | ,, | 1380/10 | 100/100/15 | 350/10 | 89220 | 249 |
| ,, | 690/10 | 80/80/10 | 300/30 | 51690 | 241 | ,, | 1380/10 | 100/100/15 | 400/10 | 93360 | 257 |
| ,, | 690/10 | 100/100/15 | 400/30 | 71904 | 328 | ,, | 1280/10 | 100/100/12 | 300/60 | 205660 | 460 |
| 0 800 | 800/8 | 70/70/10 | .. | 16350 | 91 | 1·500 | 1500/10 | 100/100/12 | .. | 60100 | 187 |
| ,, | 800/8 | 80/80/10 | .. | 17922 | 97 | ,, | 1430/10 | 100/100/12 | 300/10 | 87100 | 242 |
| ,, | 800/10 | 100/100/12 | .. | 25116 | 133 | ,, | 1480/10 | 100/100/12 | 400/10 | 96100 | 250 |
| ,, | 780/10 | 70/70/10 | 200/10 | 25938 | 133 | ,, | 1480/10 | 100/100/15 | 400/10 | 101916 | 264 |
| ,, | 780/10 | 80/80/10 | 250/10 | 29766 | 147 | ,, | 1380/10 | 100/100/12 | 400/60 | 276100 | 467 |
| ,, | 780/10 | 80/80/10 | 300/10 | 32106 | 154 | | | | | | |

TABLE III. (14).—MOMENT OF RESISTANCE OF FOUR ANGLE-IRONS (TWO TO EACH FLANGE) FOR R = 6000000.

| Height. | Angle-iron of | Angle-iron of | Height. | Angle-iron of | Angle-iron of |
|---|---|---|---|---|---|
| m. | | | m. | | |
| 0·400 | 5703 | 8131 | 0·960 | 15662 | 23007 |
| 0·410 | 5757 | 8389 | 0·970 | 15841 | 23276 |
| 0·420 | 6053 | 8649 | 0·980 | 16020 | 23544 |
| 0·430 | 6229 | 8909 | 0·990 | 16200 | 23813 |
| 0·440 | 6405 | 9169 | 1·000 | 16380 | 24082 |
| 0·450 | 6580 | 9430 | 1·010 | 16559 | 24350 |
| 0·460 | 6756 | 9692 | 1·020 | 16738 | 24620 |
| 0·470 | 6933 | 9953 | 1·030 | 16917 | 24888 |
| 0·480 | 7109 | 10216 | 1·040 | 17096 | 25157 |
| 0·490 | 7285 | 10479 | 1·050 | 17275 | 25426 |
| 0·500 | 7462 | 10741 | 1·060 | 17454 | 25695 |
| 0·510 | 7639 | 11004 | 1·070 | 17633 | 25965 |
| 0·520 | 7816 | 11267 | 1·080 | 17813 | 26234 |
| 0·530 | 7993 | 11531 | 1·090 | 17992 | 26503 |
| 0·540 | 8170 | 11795 | 1·100 | 18171 | 26772 |
| 0·550 | 8347 | 12059 | 1·110 | 18351 | 27041 |
| 0·560 | 8524 | 12323 | 1·120 | 18530 | 27310 |
| 0·570 | 8702 | 12588 | 1·130 | 18710 | 27579 |
| 0·580 | 8879 | 12853 | 1·140 | 18889 | 27848 |
| 0·590 | 9057 | 13118 | 1·150 | 19068 | 28117 |
| 0·600 | 9235 | 13383 | 1·160 | 19247 | 28386 |
| 0·610 | 9412 | 13648 | 1·170 | 19427 | 28655 |
| 0·620 | 9590 | 13914 | 1·180 | 19606 | 28925 |
| 0·630 | 9768 | 14180 | 1·190 | 19785 | 29195 |
| 0·640 | 9946 | 14446 | 1·200 | 19965 | 29464 |
| 0·650 | 10124 | 14712 | 1·210 | 20144 | 29733 |
| 0·660 | 10302 | 14978 | 1·220 | 20324 | 30003 |
| 0·670 | 10480 | 15244 | 1·230 | 20503 | 30272 |
| 0·680 | 10658 | 15510 | 1·240 | 20683 | 30542 |
| 0·690 | 10836 | 15777 | 1·250 | 20862 | 30811 |
| 0·700 | 11014 | 16044 | 1·260 | 21041 | 31081 |
| 0·710 | 11192 | 16311 | 1·270 | 21220 | 31350 |
| 0·720 | 11370 | 16578 | 1·280 | 21400 | 31620 |
| 0·730 | 11549 | 16845 | 1·290 | 21580 | 31889 |
| 0·740 | 11727 | 17112 | 1·300 | 21760 | 32159 |
| 0·750 | 11906 | 17379 | 1·310 | .. | 32428 |
| 0·760 | 12085 | 17646 | 1·320 | .. | 32698 |
| 0·770 | 12264 | 17914 | 1·330 | .. | 32968 |
| 0·780 | 12443 | 18182 | 1·340 | .. | 33237 |
| 0·790 | 12622 | 18450 | 1·350 | .. | 33507 |
| 0·800 | 12800 | 18717 | 1·360 | .. | 33776 |
| 0·810 | 12973 | 18985 | 1·370 | .. | 34046 |
| 0·820 | 13157 | 19253 | 1·380 | .. | 34315 |
| 0·830 | 13336 | 19520 | 1.390 | .. | 34585 |
| 0·840 | 13515 | 19788 | 1·400 | .. | 34855 |
| 0·850 | 13694 | 20056 | 1·410 | .. | 35125 |
| 0·860 | 13873 | 20324 | 1·420 | .. | 35395 |
| 0·870 | 14052 | 20592 | 1·430 | .. | 35665 |
| 0·880 | 14230 | 20860 | 1·440 | .. | 35935 |
| 0·890 | 14409 | 21128 | 1·450 | .. | 36205 |
| 0·900 | 14588 | 21397 | 1·460 | .. | 36475 |
| 0·910 | 14767 | 21665 | 1·470 | .. | 36745 |
| 0·920 | 14946 | 21933 | 1·480 | .. | 37015 |
| 0·930 | 15125 | 22202 | 1·490 | .. | 37285 |
| 0·940 | 15304 | 22470 | 1·500 | .. | 37555 |
| 0·950 | 15483 | 22738 | | | |

TABLE IV. (20).—TABLE OF SECTIONS FOR

| | | $h = 0^m \cdot 200$. | $h = 0^m \cdot 250$. | $h = 0^m \cdot 300$. | $h = 0^m \cdot 350$. |
|---|---|---|---|---|---|
| $l = 1^m \cdot 500$ (M = 2765) | Vertical rib .. .. | 200/10 | 250/8 | .. | .. |
| | Angle-irons .. .. | 80/80/10 | 70/70/8 | .. | .. |
| | P .. .. .. .. | 57[k] | 45 | .. | .. |
| $l = 1^m \cdot 750$ (M = 3255) | Vertical rib .. .. | 200/12 | 250/8 | .. | .. |
| | Angle-irons .. .. | 110/70/10 | 70/70/10 | .. | .. |
| | P .. .. .. .. | 66 | 52 | .. | .. |
| $l = 2^m \cdot 000$ (M = 3750) | Vertical rib .. .. | 200/10 | 250/10 | 300/7 | .. |
| | Angle-irons .. .. | 110/70/11 | 80/80/10 | 70/70/8 | .. |
| | P .. .. .. .. | 70 | 62 | 46 | .. |
| $l = 2^m \cdot 250$ (M = 4255) | Vertical rib .. .. | 180/10 | 250/8 | 300/8 | .. |
| | Angle-irons .. .. | 60/60/10 | 110/70/10 | 70/70/10 | .. |
| | Flanges .. .. | 230/10 | .. | .. | .. |
| | P .. .. .. .. | 79 | 65 | 57 | .. |
| $l = 2^m \cdot 500$ (M = 4930) | Vertical rib .. .. | 176/10 | 250/12 | 300/10 | 350/6 · |
| | Angle-irons .. .. | 60/60/10 | 110/70/11 | 30/30/10 | 70/70/10 |
| | Flanges .. .. | 250/12 | .. | .. | .. |
| | P .. .. .. .. | 90 | 78 | 66 | 54 |
| $l = 2^m \cdot 750$ (M = 5825) | Vertical rib .. .. | .. | 230/10 | 300/6 | 350/8 |
| | Angle-irons .. .. | .. | 80/80/10 | 110/70/11 | 80/80/10 |
| | Flanges .. .. | .. | 200/10 | .. | .. |
| | P .. .. .. .. | .. | 90 | 68 | 66 |
| $l = 3^m \cdot 000$ (M = 6735) | Vertical rib .. .. | .. | 226/8 | 280/7 | 350/8 |
| | Angle-irons .. .. | .. | 70/70/10 | 70/70/10 | 110/70/10 |
| | Flanges .. .. | .. | 250/12 | 200/10 | .. |
| | P .. .. .. .. | .. | 97 | 82 | 70 |
| $l = 3^m \cdot 250$ (M = 7670) | Vertical rib .. .. | .. | 220/10 | 234/10 | 334/7 |
| | Angle-irons .. .. | .. | 70/70/10 | 80/80/10 | 70/70/10 |
| | Flanges { 1st plate | .. | 250/7 | 250/8 sr $2^m \cdot 60$ | 200/8 sr $2^m \cdot 50$ |
| | Flanges { 2nd plate | .. | 250/8 sr $2^m \cdot 60$ | .. | .. |
| | P .. .. .. .. | .. | 104 | 91 | 75 |
| $l = 3^m \cdot 500$ (M = 8305) | Vertical rib .. .. | .. | .. | 280/8 | 334/6 |
| | Angle-irons .. .. | .. | .. | 70/70/10 | 70/70/10 |
| | Flanges .. .. | .. | .. | 300/10 | 250/8 sr $2^m \cdot 80$ |
| | P .. .. .. .. | .. | .. | 100 | 80 |
| $l = 3^m \cdot 750$ (M = 9570) | Vertical rib .. .. | .. | .. | 260/8 | 324/8 |
| | Angle-irons .. .. | .. | .. | 70/70/10 | 70/70/10 |
| | Flanges { 1st plate | .. | .. | 210/10 | 200/13 sr $3^m \cdot 10$ |
| | Flanges { 2nd plate | .. | .. | 210/10 sr $2^m \cdot 70$ | .. |
| | P .. .. .. .. | .. | .. | 109 | 93 |
| $l = 4^m \cdot 000$ (M = 10530) | Vertical rib .. .. | .. | .. | 280/10 | 330/8 |
| | Angle-irons .. .. | .. | .. | 100/100/12 | 80/80/10 |
| | Flanges .. .. | .. | .. | 300/10 sr $3^m \cdot 10$ | 270/10 sr $3^m \cdot 10$ |
| | P .. .. .. .. | .. | .. | 126 | 98 |
| $l = 4^m \cdot 250$ (M = 11515) | Vertical rib .. .. | .. | .. | 272/6 | 320/7 |
| | Angle-irons .. .. | .. | .. | 80/80/10 | 80/80/10 |
| | Flanges { 1st plate | .. | .. | 300/14 | 250/7 |
| | Flanges { 2nd plate | .. | .. | .. | 250/8 sr $3^m \cdot 00$ |
| | P .. .. .. .. | .. | .. | 120 | 111 |
| $l = 4^m \cdot 500$ (M = 18500) | Vertical rib .. .. | .. | .. | 250/10 | 310/8 |
| | Angle-irons .. .. | .. | .. | 80/80/10 | 70/70/10 |
| | Flanges { 1st plate | .. | .. | 250/12 | 250/10 |
| | Flanges { 2nd plate | .. | .. | 250/13 sr $3^m \cdot 30$ | 250/10 sr $3^m \cdot 20$ |
| | P .. .. .. .. | .. | .. | 147 | 124 |
| $l = 5^m \cdot 000$ (M = 14500) | Vertical rib .. .. | .. | .. | .. | 314/7 |
| | Angle-irons .. .. | .. | .. | .. | 80/80/10 |
| | Flanges { 1st plate | .. | .. | .. | 300/9 |
| | Flanges { 2nd plate | .. | .. | .. | 300/9 sr $3^m \cdot 40$ |
| | P .. .. .. .. | .. | .. | .. | 131 |

DOUBLE-FLANGED MINOR LONGITUDINAL GIRDERS.

| $h = 0^m \cdot 400$. | $h = 0^m \cdot 450$. | $h = 0^m \cdot 500$. | $h = 0^m \cdot 550$. | $h = 0^m \cdot 600$. | $h = 0^m \cdot 650$. | $h = 0^m \cdot 700$. |
|---|---|---|---|---|---|---|
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 400/6 | .. | .. | .. | .. | .. | .. |
| 70/70/10 | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 56 | .. | .. | .. | .. | .. | .. |
| 400/7 | 450/6 | .. | .. | .. | .. | .. |
| 80/80/10 | 70/70/10 | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 66 | 60 | .. | .. | .. | .. | .. |
| 400/10 | 450/6 | .. | .. | .. | .. | .. |
| 80/80/11 | 80/80/10 | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 80 | 65 | .. | .. | .. | .. | .. |
| 400/8 | 450/10 | 500/8 | .. | .. | .. | .. |
| 110/70/11 | 80/80/10 | 70/70/10 | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 80 | 80 | 70 | .. | .. | .. | .. |
| 400/8 | 450/12 | 500/8 | .. | .. | .. | .. |
| 100/100/12 | 80/80/11 | 80/80/10 | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 93 | 92 | 76 | .. | .. | .. | .. |
| 380/10 | 450/6 | 500/8 | 550/8 | 600/7 | .. | .. |
| 70/70/10 | 100/100/12 | 110/70/10 | 80/80/10 | 70/70/10 | .. | .. |
| 200/10 s$^r$ 3$^m$·00 | .. | .. | .. | .. | .. | .. |
| 92 | 89 | 83 | 80 | 72 | .. | .. |
| 384/8 | 432/8 | 500/8 | 550/10 | 600/7 | .. | .. |
| 80/80/10 | 70/70/10 | 110/70/11 | 80/80/10 | 80/80/10 | .. | .. |
| 280/8 s$^r$ 3$^m$·20 | 200/9 s$^r$ 3$^m$·10 | .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 95 | 87 | 90 | 88 | 73 | .. | .. |
| 380/7 | 434/8 | 484/8 | 538/8 | 600/10 | 650/6 | .. |
| 80/80/10 | 80/80/10 | 70/70/10 | 70/70/8 | 80/80/10 | 80/80/10 | .. |
| 300/10 s$^r$ 3$^m$·70 | 250/8 s$^r$ 3$^m$·20 | 200/8 s$^r$ 3$^m$·10 | 180/6 s$^r$ 2$^m$·70 | .. | .. | .. |
| .. | .. | .. | .. | .. | .. | .. |
| 105 | 94 | 87 | 76 | 92 | 76 | .. |
| 374/8 | 426/8 | 484/8 | 532/8 | 600/6 | 650/10 | 700/8 |
| 80/80/10 | 80/80/10 | 80/80/10 | 70/70/10 | 100/100/12 | 80/80/10 | 80/80/10 |
| 300/13 s$^r$ 4$^m$·20 | 240/6 s$^r$ 4$^m$·00 | 250/8 s$^r$ 3$^m$·50 | 200/9 s$^r$ 3$^m$·50 | .. | .. | .. |
| .. | 246/6 s$^r$ 2$^m$·80 | .. | .. | .. | .. | .. |
| 120 | 94 | 97 | 92 | 96 | 96 | 90 |

TABLE V. (23).—CROSS-GIRDERS FOR THREE-GIRDER BRIDGES.

| Distance between the Cross-girders, and Moments of Rupture. | Height of the Cross-girder. | Section. | | | | | Weight | |
|---|---|---|---|---|---|---|---|---|
| | | Vertical Rib. | Angle-irons. | Flanges. | | | Of a Cross-girder to one line of Rails. | Of the Cross-girders the Lineal Mètre of Flooring under two lines of Rails. |
| | | | | First Plate of 4 mètres long. | Second Plate. | Third Plate. | | |
| | m. | mill. | mill. | | | | kilos. | kilos. |
| 1m·500 | 0·300 | 260/10 | 80/80/10 | 280/10 | 280/10 sr 3m·000 | .. | 670 | 895 |
| (M = 12090) | 0·350 | 310/8 | 70/70/10 | 240/10 | 240/10 sr 3m·000 | .. | 600 | 800 |
| | 0·400 | 380/10 | 80/80/10 | 250/10 | .. | .. | 570 | 760 |
| | 0·500 | 500/6 | 100/100/12 | .. | .. | .. | 495 | 660 |
| 2m·000 | 0·300 | 248/10 | 80/80/10 | 300/13 | 300/13 sr 3m·000 | .. | 780 | 780 |
| (M = 14950) | 0·350 | 310/10 | 80/80/10 | 300/10 | 300/10 sr 3m·000 | .. | 680 | 680 |
| | 0·400 | 376/10 | 80/80/10 | 290/12 | .. | .. | 630 | 630 |
| | 0·500 | 480/10 | 80/80/10 | 200/10 | .. | .. | 580 | 580 |
| | 0·600 | 600/6 | 100/100/12 | .. | .. | .. | 530 | 530 |
| 2m·500 | 0·300 | 240/12 | 80/80/10 | 300/10 | 300/10 sr 3m·400 | 300/10 sr 2m·600 | 840 | 670 |
| (M = 16500) | 0·400 | 360/10 | 80/80/10 | 250/10 | 250/10 sr 2m·800 | .. | 670 | 540 |
| | 0·500 | 480/10 | 80/80/10 | 260/10 | .. | .. | 620 | 500 |
| | 0·600 | 600/10 | 100/100/12 | .. | .. | .. | 610 | 490 |
| 3m·000 | 0·400 | 380/10 | 100/100/12 | 350/10 | .. | .. | 730 | 490 |
| (M = 17800) | 0·500 | 484/8 | 100/100/12 | 250/8 | .. | .. | 650 | 435 |
| | 0·600 | 580/10 | 70/70/10 | 200/10 | .. | .. | 600 | 400 |
| | 0·700 | 700/6 | 100/100/12 | .. | .. | .. | 560 | 375 |
| 3m·500 | 0·400 | 360/10 | 80/80/10 | 300/10 | 300/11 sr 2m·800 | .. | 740 | 425 |
| (M = 19240) | 0·500 | 480/8 | 100/100/12 | 250/10 | .. | .. | 680 | 390 |
| | 0·600 | 580/6 | 80/80/10 | 250/10 | .. | .. | 580 | 370 |
| | 0·700 | 700/7 | 100/100/12 | .. | .. | .. | 580 | 370 |
| | 0·800 | 800/8 | 80/80/11 | .. | .. | .. | 570 | 325 |
| 4m·000 | 0·400 | 360/10 | 100/100/12 | 300/10 | 300/10 sr 2m·700 | .. | 820 | 410 |
| (M = 20540) | 0·500 | 480/8 | 100/100/12 | 300/10 | .. | .. | 710 | 355 |
| | 0·600 | 580/10 | 80/80/10 | 250/10 | .. | .. | 660 | 330 |
| | 0·700 | 700/10 | 100/100/12 | .. | .. | .. | 655 | 330 |
| | 0·800 | 800/10 | 80/80/11 | .. | .. | .. | 620 | 310 |
| | 0·850 | 850/8 | 80/80/11 | .. | .. | .. | 590 | 295 |
| 4m·500 | 0·500 | 460/10 | 80/80/10 | 250/10 | 250/10 sr 2m·700 | .. | 715 | 320 |
| (M = 21700) | 0·600 | 580/8 | 80/80/10 | 300/10 | .. | .. | 650 | 290 |
| | 0·700 | 700/10 | 100/100/12 | .. | .. | .. | 655 | 290 |
| | 0·900 | 900/8 | 80/80/11 | .. | .. | .. | 610 | 270 |
| 5m·000 | 0·600 | 580/8 | 80/80/10 | 340/10 | .. | .. | 675 | 270 |
| (M = 22750) | 0·700 | 680/8 | 80/80/10 | 220/10 | .. | .. | 645 | 260 |
| | 0·800 | 800/7 | 100/100/12 | .. | .. | .. | 620 | 250 |
| | 0·900 | 900/8 | 80/80/12 | .. | .. | .. | 625 | 250 |

TABLE VI. (24).—CROSS-GIRDERS FOR TWO-GIRDER BRIDGES.

| Distance between the Cross-girders, and Moments of Rupture. | Height of the Cross-girder. | Section. | | | | | Weight of the Cross-girders the Lineal Mètre of Flooring. |
|---|---|---|---|---|---|---|---|
| | | Vertical Rib. | Angle-irons. | Flanges. | | | |
| | | | | First Plate. | Second Plate. | Third Plate. | |
| | m. | | | | | | kilos. |
| 2m·000 | 0·600 | 540/10 | 80/80/10 | 310/10 | 310/10 sr 6m·300 | 310/10 sr 5m·000 | 870 |
| (M = 40250) | 0·700 | 640/10 | 80/80/10 | 250/10 | 250/10 sr 6m·000 | 250/10 sr 5m·000 | 840 |
| | 0·800 | 740/10 | 70/70/10 | 200/10 | 200/10 sr 5m·800 | 200/10 sr 4m·800 | 820 |
| | 0·900 | 880/10 | 80/80/10 | 320/10 | .. | .. | 785 |
| 3m·000 | 0·600 | 540/10 | 100/100/15 | 350/10 | 350/10 sr 6m·200 | 350/10 sr 5m·200 | 740 |
| (M = 47950) | 0·800 | 740/10 | 80/80/10 | 250/10 | 250/10 sr 6m·000 | 250/10 sr 4m·800 | 600 |
| | 1·000 | 974/10 | 80/80/10 | 300/13 sr 6m·000 | .. | .. | 530 |
| 4m·000 | 0·800 | 740/10 | 80/80/10 | 300/10 | 300/10 sr 6m·200 | 300/10 sr 5m·000 | 490 |
| (M = 55300) | 1·000 | 1000/8 | 100/100/12 | 220/9 sr 5m·800 | 220/9 sr 4m·500 | .. | 410 |
| | 1·000 | 1000/8 | 80/80/10 | 250/10 | 250/10 sr 4m·800 | .. | 400 |
| 5m·000 | 1·000 | 1000/8 | 100/100/12 | 250/10 sr 6m·000 | 250/10 sr 4m·600 | .. | 340 |
| (M = 61250) | | | | | | | |

TABLE VII. (31).—CROSS-GIRDERS FOR ROAD BRIDGES.

| Bearing of the Cross-girder. | Height of the Cross-girder. | Distance between the principal Girders. | Moment of Rupture. | Section. | | | | Weight of the Cross-girders the Lineal Mètre of Flooring. |
|---|---|---|---|---|---|---|---|---|
| | | | | Vertical Rib. | Angle-irons. | Flanges. | | |
| | | | | | | First Plate. | Second Plate. | |
| mètres. | m. | m. | | mill. | mill. | | | kilos. |
| 3·000 | 0·250 | 3·400 | 3600 | 250/8 | 80/80/10 | .. | .. | 120 |
| ,, | 0·300 | ,, | ,, | 300/6 | 60/60/10 | .. | .. | 100 |
| 4·000 | 0·300 | 4·400 | 5910 | 300/7 | 110/70/11 | .. | .. | 190 |
| ,, | 0·350 | ,, | ,, | 350/6 | 110/70/10 | .. | .. | 180 |
| 5·000 | 0·300 | 5·400 | 10625 | 274/10 | 80/80/10 | 300/13 sr 4m·300 in length. | .. | 350 |
| ,, | 0·400 | ,, | ,, | 380/8 | 80/80/10 | 200/10 sr 3m·600 | .. | 275 |
| 6·000 | 0·350 | 6·400 | 13500 | 310/8 | 80/80/10 | 250/10 sr the entire length. | 250/10 sr 4m·000 | 460 |
| ,, | 0·400 | ,, | ,, | 374/8 | 80/80/10 | 250/13 sr 5m·000 | .. | 395 |
| 7·000 | 0·400 | 7·400 | 16625 | 356/8 | 80/80/10 | 250/11 sr the entire length. | 250/11 sr 4m·800 | 565 |
| ,, | 0·500 | ,, | ,, | 476/8 | 80/80/10 | 240/12 sr 5m·400 | .. | 455 |
| 8·000 | 0·500 | 8·400 | 20000 | 476/8 | 100/100/12 | 220/12 sr 5m·500 | .. | 600 |

TABLE VIII.—FORMULÆ OF STRAINS AND WEIGHTS.

| | General Case. | Case in which $\alpha = \beta$. |
|---|---|---|
| *1st Arrangement* (Fig. 1657). $l = 2m\,\delta$. | | |
| Strain upon the $n$th strut | $\frac{\delta}{2 \sin. \alpha}\left[(2n-1)\,p + \frac{(m+n)\,(m+n-1)}{2m}\,p'\right]$ | $\frac{\delta}{2 \sin. \alpha}\left[(2n-1)\,p + \frac{(m+n)\,(m+n-1)}{2m}\,p'\right]$ |
| ,, $n$th brace | $\frac{\delta}{2 \sin. \beta}\left[(2n-1)\,p + \frac{(m+n)\,(m+n-1)}{2m}\,p'\right]$ | —— |
| ,, $n$th section of upper flange | $(m-n+1)\,(m+n-1)\,(p+p')\,\frac{\delta^2}{2h}$ | $(m-n+1)\,(m+n-1)\,(p+p')\,\frac{\delta^2}{2h}$ |
| , $n$th section of lower flange | $(p+p')\,\delta\left[(m^2-n^2)\,\frac{\delta}{2h} + \frac{2n-1}{2\,tg.\,\alpha}\right]$ | $\left(m-n+\frac{1}{2}\right)\left(m+n-\frac{1}{2}\right)(p+p')\,\frac{\delta^2}{2h}$ |
| Maximum strain in the middle of the upper flange | $\frac{m^2\,(p+p')\,\delta^2}{2h}$ or $(p+p')\,\frac{l^2}{8h}$ | $(p+p')\,\frac{l^2}{8h}$ |
| ,, ,, lower flange | $\frac{(p+p')\,\delta}{2}\left[(m^2-1)\,\frac{\delta}{h} + \frac{1}{tg.\,\alpha}\right]$ | $(2m^2-1)\,(p+p')\,\frac{\delta^2}{4h}$ |
| Total weight of the $2m$ struts | $\frac{\delta\,h\,t\,V}{\sin.^2\alpha}\left[m^2 p + \frac{7m^2-1}{6}\,p'\right]$ | $\frac{\delta\,h\,t\,V}{\sin.^2\alpha}\left(m^2 p + \frac{7m^2-1}{6}\,p'\right)$ |
| ,, braces | $\frac{\delta\,h\,t}{\sin.^2\beta}\left(m^2 p + \frac{7m^2-1}{6}\,p'\right)$ | $\frac{\delta\,h\,t}{\sin.^2\alpha}\left(m^2 p + \frac{7m^2-1}{6}\,p'\right)$ |
| Total weight of the upper flange | $m\,(p+p')\,\delta^2\,t\,U\left[(4m-1)\,(m+1)\,\frac{\delta}{6h} - \frac{m}{tg.\,\alpha}\right]$ | $m\,(4m^2-1)\,(p+p')\,\frac{\delta^3\,t\,U}{6h}$ |
| ,, lower flange | $m\,(p+p')\,\delta^2\,t\,U\left[(4m+1)\,(m-1)\,\frac{\delta}{6h} + \frac{m}{tg.\,\alpha}\right]$ | —— |
| ,, two flanges together | $m\,(4m^2-1)\,(p+p')\,\frac{\delta^3\,t\,U}{3h}$ | $m\,(4m^2-1)\,(p+p')\,\frac{\delta^3\,t\,U}{3h}$ |
| *2nd Arrangement* (Fig. 1658). $l = (2m+1)\,\delta$. | | |
| Strain upon the $n$th strut | $\frac{\delta}{\sin. \alpha}\left[np + \frac{(m+n)\,(m+n+1)}{2\,(2m+1)}\,p'\right]$ | $\frac{\delta}{\sin. \alpha}\left[np + \frac{(m+n)\,(m+n+1)}{2\,(2m+1)}\,p'\right]$ |
| ,, $n$th brace | $\frac{\delta}{\sin. \beta}\left[np + \frac{(m+n)\,(m+n+1)}{2\,(2m+1)}\,p'\right]$ | —— |

| | | |
|---|---|---|
| Strain upon the $n$th section of upper flange .. .. .. | $(m+n).(m-n+1)\,(p+p')\,\frac{\delta^2}{2h}$ | $(m+n)\,(m-n+1)\,(p+p')\,\frac{\delta^2}{2h}$ |
| ,, $n$th section of lower flange .. .. .. | $(p+p')\,\delta\left[(m+n)\,(m-n+1)\,\frac{\delta}{2h}+\frac{n-1}{tg.\,\alpha}\right]$ | $(m^2-n^2+m+2n-1)\,(p+p')\,\frac{\delta^2}{2h}$ |
| Maximum strain in the middle of the flanges .. .. | $m\,(m+1)\,(p+p')\,\frac{\delta^2}{2h}$ | $m\,(m+1)\,(p+p')\,\frac{\delta^2}{2h}$ |
| Total weight of the 2 $m$ struts .. .. .. .. .. | $\frac{m\,(m+1)\,\delta\,h\,t\,V}{\sin.^2\alpha}\left(p+\frac{7}{6}\,p'\right)$ | $\frac{m\,(m+1)\,\delta\,h\,t\,V}{\sin.^2\alpha}\left(p+\frac{7}{6}\,p'\right)$ |
| , braces .. .. .. .. .. | $\frac{m\,(m+1)\,\delta\,h\,t}{\sin.^2\beta}\left(p+\frac{7}{6}\,p'\right)$ | $\frac{m\,(m+1)\,\delta\,h\,t}{\sin.^2\alpha}\left(p+\frac{7}{6}\,p'\right)$ |
| Total weight of the upper flange .. .. .. .. .. | $m\,(p+p')\,\delta^2\,t\,U\left[(4m+5)\,(m+1)\,\frac{\delta}{6h}-\frac{m+1}{tg.\,\alpha}\right]$ | $m\,(m+1)\,(2m+1)\,(p+p')\,\frac{\delta^3\,t\,U}{3h}$ |
| ,, lower flange .. .. .. .. .. | $m\,(p+p')\,\delta^2\,t\,U\left[(4m-1)\,(m+1)\,\frac{\delta}{6h}+\frac{m+1}{tg.\,\alpha}\right]$ | —— |
| ,, two flanges together .. .. .. | $\frac{2}{3}\,m\,(m+1)\,(2m+1)\,(p+p')\,\frac{\delta^3\,t\,U}{h}$ | $\frac{2}{3}\,m\,(m+1)\,(2m+1)\,(p+p')\,\frac{\delta^3\,t\,U}{h}$ |

TABLE IX. A (91).—GIRDERS LIGHTLY LOADED ON THE LOWER SIDE $\left(\frac{h}{l}=0{\cdot}11,\ U=1{\cdot}40,\ V=1{\cdot}35\right)$.

| $q=$ | N = 5. | N = 6. | N = 7. | N = 8. | N = 9. | N = 10. | N = 11. | N = 12. | N = 13. | N = 14. | N = 15. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0·40 | 0·003440 | 0·003521 | 0·003575 | 0·003659 | 0·003723 | 0·003809 | 0·003879 | 0·003966 | 0·004049 | 0·004064 | 0·004045 |
| 0·50 | 0·003453 | 0·003533 | 0·003589 | 0·003673 | 0·003739 | 0·003825 | 0·003897 | 0·003985 | 0·004069 | 0·004085 | 0·004066 |
| 0·60 | 0·003465 | 0·003545 | 0·003602 | 0·003687 | 0·003755 | 0·003841 | 0·003915 | 0·004003 | 0·004090 | 0·004105 | 0·004086 |
| 0·70 | 0·003477 | 0·003557 | 0·003616 | 0·003701 | 0·003770 | 0·003857 | 0·003933 | 0·004022 | 0·004110 | 0·004125 | 0·004106 |
| 0·80 | 0·003489 | 0·003568 | 0·003630 | 0·003715 | 0 003786 | 0·003874 | 0·003951 | 0·004041 | 0·004130 | 0·004145 | 0·004127 |

TABLE IX. B $\left(\text{Value of } \frac{P}{(p+p')\,l^2}\right)$.—GIRDERS HEAVILY LOADED ON THE LOWER SIDE $\left(\frac{h}{l}=\frac{1}{8},\ U=130,\ V=125\right)$.

| | | N = 5. | N = 6. | N = 7. | N = 8. | N = 9. | N = 10. | N = 11. | N = 12. | N = 13. | N = 14. | N = 15. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $q=$ | 0·40 | 0·002931 | 0·003030 | 0·003094 | 0·003189 | 0·003263 | 0·003359 | 0·003439 | 0·003535 | 0·003619 | 0·003716 | 0·003803 |
| | 0·50 | 0·002943 | 0·003042 | 0·003108 | 0·003204 | 0·003280 | 0·003376 | 0·003458 | 0·003555 | 0·003641 | 0·003739 | 0·003827 |
| | 0·60 | 0·002955 | 0·003053 | 0·003122 | 0·003218 | 0·003296 | 0·003393 | 0·003477 | 0·003575 | 0·003662 | 0·003762 | 0·003852 |
| | 0·70 | 0·002967 | 0·003065 | 0·003136 | 0·003232 | 0·003312 | 0·003410 | 0·003496 | 0·003595 | 0·003684 | 0·003784 | 0·003876 |
| | 0·80 | 0·002979 | 0·003077 | 0·003150 | 0·003246 | 0·003328 | 0·003427 | 0·003514 | 0·003615 | 0·003705 | 0·003807 | 0·003900 |

For TABLES X. A, X. B, see page 827.

TABLE XI. (167).—ARCHED GIRDERS OF TENSION-CROSSES $\left(\text{Values of } \frac{P}{(p+p')\,l^2}\right)$

| | | N = 5. | N = 6. | N = 7. | N = 8. | N = 9. | N = 10. | N = 11. | N = 12. | N = 13. | N = 14. | N = 15. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $q=$ | 0·40 | 0·003116 | 0·003148 | 0·003154 | 0·003171 | 0·003178 | 0·003192 | 0·003200 | 0·003212 | 0·003221 | 0·003233 | 0·003243 |
| | 0·50 | 0·003165 | 0·003186 | 0·003201 | 0·003213 | 0·003226 | 0·003238 | 0·003251 | 0·003263 | 0·003277 | 0·003289 | 0·003303 |
| | 0·60 | 0·003215 | 0·003224 | 0·003248 | 0·003255 | 0·003275 | 0·003284 | 0·003303 | 0·003314 | 0·003332 | 0·003345 | 0·003364 |
| | 0·70 | 0·003265 | 0·003262 | 0·003295 | 0·003297 | 0·003323 | 0·003330 | 0·003354 | 0·003364 | 0·003388 | 0·003400 | 0·003424 |
| | 0·80 | 0·003314 | 0·003300 | 0·003343 | 0·003338 | 0·003372 | 0·003376 | 0·003406 | 0·003415 | 0·003443 | 0·003456 | 0·003484 |

TABLE XII.—WEIGHT OF THE LINEAL MÈTRE OF RAILWAY BRIDGES UNDER TWO LINES OF RAILS.
(See 181–191.)

## Case of Limited Height (Girders Loaded on the Lower Side, or the Tubular System).

### Table XII. A.—Three-girder Bridges.

### Table XII. B.—Two-girder Bridges.

| | | Height | | Weight the Mètre of Total Length | | | | Total the Lineal Mètre of Bearing. | Height of the Girders. | Weight the Mètre of Total Length | | | Total the Lineal Mètre of Bearing. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Of the Outside Girders. | Of the Middle Girder. | Of the Two Outside Girders. | Of the Middle Girder. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | | | Of the Two Girders. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | |
| | | mètres. | mètres. | kilos. | kilos. | kilos. | kilos. | kilos. | mètres. | kilos. | kilos. | kilos. | kilos. |
| Solid girders. | $l$ = 20 m. | 1·70 | 2·30 | 740 | 480 | 640 | 2050 | 2140 | 2·00 | 970 | 750 | 1890 | 1980 |
| | 30 | 2·30 | 3·00 | 1220 | 780 | 720 | 3000 | 3110 | 2·70 | 1600 | 810 | 2650 | 2770 |
| | 40 | 2·90 | 3·50 | 1740 | 1100 | 730 | 3930 | 4110 | 3·30 | 2300 | 820 | 3430 | 3580 |
| | 50 | 3·30 | 3·50 | 2300 | 1500 | 740 | 5000 | 5220 | 3·60 | 3000 | 830 | 4210 | 4400 |
| Multiple lattice-girders. | $l$ = 20 | 2·20 | 2·50 | 670 | 470 | 640 | 1960 | 2050 | 2·40 | 900 | 750 | 1820 | 1900 |
| | 30 | 3·30 | 3·75 | 1000 | 700 | 720 | 2660 | 2780 | 3·50 | 1320 | 810 | 2340 | 2450 |
| | 40 | 3·30 | 3·75 | 1450 | 1000 | 730 | 3500 | 3660 | 3·60 | 2000 | 820 | 3100 | 3240 |
| | 40 | 5·30 | 5·30 | 1250 | 800 | 880 | 3220 | 3370 | 5·60 | 1780 | 1050 | 3110 | 3250 |
| | 50 | 5·70 | 5·70 | 1650 | 1000 | 880 | 3880 | 4060 | 6·00 | 2240 | 1050 | 3620 | 3780 |
| | 60 | 7·00 | 7·00 | 2000 | 1200 | 880 | 4490 | 4690 | 7·20 | 2800 | 1060 | 4250 | 4440 |
| | 70 | 8·00 | 8·00 | 2450 | 1460 | 900 | 5290 | 5530 | 8·50 | 3500 | 1080 | 5040 | 5270 |
| | 80 | 9·00 | 9·00 | 2900 | 1750 | 930 | 6140 | 6420 | 9·70 | 4200 | 1100 | 5830 | 6090 |
| Triangular lattice-girders. | $l$ = 40 | 5·30 | 5·30 | 1070 | 730 | 880 | 2950 | 3080 | 5·60 | 1500 | 1050 | 2800 | 2930 |
| | 50 | 5·70 | 5·70 | 1360 | 920 | 880 | 3180 | 3640 | 6·00 | 1860 | 1050 | 3200 | 3340 |
| | 60 | 7·00 | 7·00 | 1640 | 1100 | 880 | 3980 | 4160 | 7·20 | 2350 | 1060 | 3750 | 3920 |
| | 70 | 8·00 | 8·00 | 2000 | 1360 | 900 | 4690 | 4900 | 8·50 | 2950 | 1080 | 4430 | 4630 |
| | 80 | 9·00 | 9·00 | 2440 | 1660 | 930 | 5530 | 5780 | 9·70 | 3600 | 1100 | 5170 | 5400 |
| Cross lattice-girders. | $l$ = 20 | 2·20 | 2·50 | 570 | 400 | 640 | 1770 | 1850 | 2·40 | 780 | 750 | 1680 | 1760 |
| | 30 | 3·30 | 3·75 | 850 | 600 | 720 | 2390 | 2500 | 3·50 | 1150 | 810 | 2160 | 2250 |
| | 40 | 5·30 | 5·30 | 950 | 700 | 880 | 2780 | 2910 | 3·60 | 1760 | 820 | 2840 | 2970 |
| | | | | | | | | | 5·60 | 1380 | 1050 | 2670 | 2790 |
| | 50 | 5·70 | 5·70 | 1300 | 900 | 880 | 3390 | 3540 | 6·00 | 1820 | 1050 | 3160 | 3300 |
| | 60 | 7·00 | 7·00 | 1560 | 1060 | 880 | 3850 | 4020 | 7·20 | 2240 | 1060 | 3630 | 3300 |
| | 70 | 8·00 | 8·00 | 1880 | 1300 | 900 | 4490 | 4690 | 8·50 | 2750 | 1080 | 4210 | 4400 |
| | 80 | 9·00 | 9·00 | 2280 | 1550 | 930 | 5240 | 5470 | 9·70 | 3300 | 1100 | 4840 | 5060 |
| Arched girders with cross-lattice. | $l$ = 20 | 3·50 at centre. | 3·50 | 500 | 370 | 640 | 1660 | 1740 | 3·60 | 740 | 750 | 1630 | 1700 |
| | 30 | 5·50 | 5·50 | 700 | 550 | 760 | 2210 | 2310 | 5·70 | 1060 | 850 | 2100 | 2200 |
| | 40 | 7·00 | 7·00 | 900 | 710 | 830 | 2680 | 2800 | 7·20 | 1400 | 960 | 2600 | 2720 |
| | 50 | 9·00 | 9·00 | 1200 | 880 | 870 | 3250 | 3390 | 9·00 | 1760 | 1000 | 3010 | 3180 |
| | 60 | 11·00 | 11·00 | 1400 | 1050 | 900 | 3690 | 3850 | 11·00 | 2200 | 1030 | 3550 | 3710 |
| | 70 | 12·50 | 12·50 | 1700 | 1280 | 930 | 4300 | 4500 | 12·50 | 2700 | 1060 | 4140 | 4330 |
| | 80 | 14·00 | 14·00 | 2000 | 1520 | 960 | 4930 | 5150 | 14·00 | 3200 | 1100 | 4730 | 4940 |

CASE OF LIMITED HEIGHT (GIRDERS LOADED ON THE LOWER SIDE, OR THE TUBULAR SYSTEM).

TABLE XII. C.—Four-girder Bridges.

| | | Height of the Girders. | Weight the Mètre of Total Length | | | Total the Lineal Mètre of Bearing. |
|---|---|---|---|---|---|---|
| | | | Of the Four Girders. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | |
| | m. | mètres. | kilos. | kilos. | kilos. | kilos. |
| Solid girders .. | $l = 20$ .. .. .. | 1·70 | 1480 | 310 | 1970 | 2060 |
| | 30 .. .. .. | 2·30 | 2440 | 330 | 3050 | 3190 |
| | 40 .. .. .. | 2·90 | 3480 | 360 | 4220 | 4410 |
| | 50 .. .. .. | 3·50 | 4560 | 380 | 5430 | 5680 |
| Multiple lattice-girders without vertical rods. | $l = 20$ .. .. .. | 2·20 | 1260 | 330 | 1750 | 1830 |
| | 30 .. .. .. | 3·30 | 1860 | 370 | 2450 | 2560 |
| | 40 .. .. .. | 4·40 | 2440 | 420 | 3150 | 3290 |
| | 50 .. .. .. | 5·50 | 3040 | 460 | 3850 | 4020 |
| Triangular lattice-girders. | $l = 20$ .. .. .. | 2·20 | 1060 | 330 | 1530 | 1600 |
| | 30 .. .. .. | 3·30 | 1620 | 370 | 2190 | 2290 |
| | 40 .. .. .. | 4·40 | 2180 | 420 | 2860 | 2990 |
| | 50 .. .. .. | 5·50 | 2720 | 460 | 3500 | 3660 |
| Cross lattice-girders without vertical rods. | $l = 20$ .. .. .. | 2·20 | 1040 | 330 | 1510 | 1580 |
| | 30 .. .. .. | 3·30 | 1540 | 370 | 2100 | 2200 |
| | 40 .. .. .. | 4·40 | 2080 | 420 | 2750 | 2870 |
| | 50 .. .. .. | 5·50 | 2600 | 460 | 3370 | 3520 |

CASE OF UNLIMITED HEIGHT (GIRDERS UNDER RAILS).

TABLE XII. D.—Three-girder Bridges.

| | | | Height of the Girders. | Weight the Mètre of Total Length | | | | Total the Lineal Mètre of Bearing. |
|---|---|---|---|---|---|---|---|---|
| | | | | Of the Two Outside Girders. | Of the Centre Girder. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | |
| | m. | | mètres. | kilos. | kilos. | kilos. | kilos. | kilos. |
| Solid girders. | $l = 20$ | First arrangement. | 1·80 | 860 | 350 | 500 | 1880 | 1970 |
| | 30 | | 2·40 | 1430 | 570 | 530 | 2780 | 2910 |
| | 40 | Second arrangement. | 3·00 | 2000 | 800 | 560 | 3700 | 3860 |
| | 40 | | 3·00 | 1860 | 950 | 850 | 4030 | 4210 |
| | 50 | | 3·60 | 2500 | 1250 | 900 | 5120 | 5350 |
| Multiple lattice-girders without vertical rods. | $l = 20$ | First arrangement. | 2·20 | 740 | 280 | 520 | 1700 | 1770 |
| | 30 | | 3·30 | 1100 | 400 | 580 | 2290 | 2390 |
| | 40 | | 4·40 | 1440 | 530 | 650 | 2880 | 3010 |
| | 40 | Second arrangement. | 4·40 | 1300 | 630 | 850 | 3060 | 3200 |
| | 50 | | 5·50 | 1660 | 800 | 900 | 3700 | 3860 |
| | 60 | | 6·70 | 2020 | 960 | 960 | 4330 | 4530 |
| | 70 | | .. | .. | .. | .. | .. | .. |
| | 80 | | .. | .. | .. | .. | .. | .. |
| Triangular lattice-girders. | $l = 20$ | First arrangement. | 2·20 | 650 | 230 | 520 | 1540 | 1610 |
| | 30 | | 3·30 | 980 | 350 | 580 | 2100 | 2200 |
| | 40 | | 4·40 | 1300 | 460 | 650 | 2650 | 2770 |
| | 40 | Second arrangement. | 4·40 | 1180 | 560 | 850 | 2850 | 2980 |
| | 50 | | 5·50 | 1500 | 710 | 900 | 3420 | 3570 |
| | 60 | | 6·70 | 1820 | 860 | 960 | 4000 | 4180 |
| | 70 | | .. | .. | .. | .. | .. | .. |
| | 80 | | .. | .. | .. | .. | .. | .. |
| Cross lattice-girders without vertical rods. | $l = 20$ | First arrangement. | 2·20 | 640 | 230 | 520 | 1530 | 1600 |
| | 30 | | 3·30 | 940 | 340 | 580 | 2050 | 2140 |
| | 40 | | 4·40 | 1240 | 440 | 650 | 2560 | 2630 |
| | 40 | Second arrangement. | 4·40 | 1120 | 540 | 850 | 2760 | 2880 |
| | 50 | | 5·50 | 1430 | 680 | 900 | 3310 | 3460 |
| | 60 | | 6·70 | 1740 | 820 | 960 | 3870 | 4050 |
| | 70 | | .. | .. | .. | .. | .. | .. |
| | 80 | | .. | .. | .. | .. | .. | .. |

TABLE XII. E.—Two-girder Bridges.

| Height of the Girders. | Weight the Mètre of Total Length | | | Total the Lineal Mètre of Bearing. |
|---|---|---|---|---|
| | Of the Two Girders. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | |
| mètres. | kilos. | kilos. | kilos. | kilos. |
| 2·15 | 980 | 550 | 1680 | 1780 |
| 2·70 | 1600 | 580 | 2400 | 2500 |
| 3·40 | 2260 | 630 | 3180 | 3320 |
| 3·40 | 2200 | 780 | 3280 | 3430 |
| 4·00 | 2900 | 800 | 4070 | 4250 |
| 2·40 | 870 | 560 | 1570 | 1640 |
| 3·60 | 1270 | 630 | 2090 | 2180 |
| 4·80 | 1680 | 700 | 2620 | 2740 |
| 4·70 | 1600 | 830 | 2670 | 2800 |
| 6·00 | 2000 | 880 | 3170 | 3310 |
| 7·00 | 2470 | 920 | 3730 | 3900 |
| 8·50 | 3060 | 980 | 4440 | 4640 |
| 9·50 | 3660 | 1020 | 5150 | 5380 |
| 2·40 | 780 | 560 | 1470 | 1540 |
| 3·60 | 1160 | 630 | 1970 | 2060 |
| 4·80 | 1540 | 700 | 2460 | 2580 |
| 4·70 | 1450 | 830 | 2510 | 2620 |
| 6·00 | 1870 | 880 | 3030 | 3160 |
| 7·00 | 2280 | 920 | 3520 | 3680 |
| 8·50 | 2900 | 980 | 4270 | 4460 |
| 9·50 | 3500 | 1020 | 4970 | 5200 |
| 2·40 | 750 | 560 | 1440 | 1500 |
| 3·60 | 1120 | 630 | 1930 | 2010 |
| 4·80 | 1480 | 700 | 2400 | 2510 |
| 4·70 | 1400 | 830 | 2450 | 2560 |
| 6·00 | 1800 | 880 | 2950 | 3080 |
| 7·00 | 2200 | 920 | 3430 | 3590 |
| 8·50 | 2700 | 980 | 4050 | 4230 |
| 9·50 | 3200 | 1020 | 4640 | 4359 |

## TABLE XIII.—WEIGHT THE LINEAL MÈTRE OF ROAD BRIDGES.

| | | A.—Roads of 6m. | | | | B.—Roads of 10m | | | | C.—Roads of 14m. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Height of the Girders. | Weight the Lineal Mètre of Total Length | | | Weight the Lineal Mètre of Bearing. | Height of the Girders. | Weight the Lineal Mètre of Total Length | | | Weight the Lineal Mètre of Bearing. | Height of the Girders. | Weight the Lineal Mètre of Total Length | | | | Weight the Lineal Mètre of Bearing. |
| | | | Of the Two Girders. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | | | Of the Two Girders. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | | | Of the Outside Girders. | Of the Centre Girder. | Of the other Pieces. | Total with the addition of $\frac{1}{10}$. | |
| *Case of Unlimited Height.* | | | | | | | | | | | | | | | | | |
| m. | | mètres. | kilos. | kilos. | kilos. | kilos. | mètres. | kilos. | kilos. | kilos. | kilos. | mètres. | kilos. | kilos. | kilos. | kilos. | kilos. |
| $l$ = 10, Figs. 1625, 1788, or 1789.. .. | Solid girders .. | 0·70 | 300 | 340 | 700 | 730 | 0·70 | 470 | 430 | 990 | 1040 | 0·90 | 350 | 200 | 750 | 1430 | 1490 |
| $l$ = 20, Figs. 1608, 1609, or 1708,. .. | Solid girders .. .. | 1·40 | 600 | 420 | 1120 | 1170 | 1·90 | 840 | 650 | 1640 | 1710 | 1·80 | 700 | 480 | 810 | 2190 | 2290 |
| | Multiple lattice-girders | 2·00 | 500 | 430 | 1020 | 1070 | 2·20 | 800 | 660 | 1610 | 1680 | 2·20 | 660 | 460 | 830 | 2150 | 2240 |
| | Cross lattice-girders .. | 2·00 | 480 | 430 | 1000 | 1050 | 2·20 | 630 | 660 | 1420 | 1480 | 2·20 | 570 | 410 | 830 | 1990 | 2080 |
| $l$ = 30, idem | Solid girders .. .. | 2·00 | 1040 | 430 | 1620 | 1690 | 2·50 | 1420 | 680 | 2310 | 2410 | .. | .. | .. | .. | .. | .. |
| | Multiple lattice-girders | 3·00 | 840 | 450 | 1420 | 1480 | 3·30 | 1240 | 740 | 2180 | 2280 | 3·40 | 1030 | 700 | 900 | 2390 | 3020 |
| | Cross lattice-girders .. | 3·00 | 720 | 450 | 1290 | 1350 | 3·30 | 980 | 740 | 1890 | 1980 | 3·40 | 350 | 610 | 900 | 2600 | 2710 |
| $l$ = 40, idem | Multiple lattice-girders | 3·80 | 1220 | 470 | 1990 | 2080 | 4·50 | 1600 | 810 | 2650 | 2770 | 4·60 | 1430 | 970 | 950 | 3690 | 3850 |
| | Cross lattice-girders .. | 3·80 | 1040 | 470 | 1660 | 1740 | 4·50 | 1350 | 810 | 2380 | 2480 | 4·60 | 1130 | 870 | 950 | 3250 | 3390 |
| $l$ = 50, idem | Multiple lattice-girders | .. | .. | .. | .. | .. | 5·80 | 2100 | 900 | 3300 | 3450 | .. | .. | .. | .. | .. | .. |
| | Cross lattice-girders .. | .. | .. | .. | .. | .. | 5·80 | 1740 | 900 | 2900 | 3030 | 5·30 | 1500 | 1150 | 1000 | 4020 | 4200 |
| *Case of Limited Height.* | | | | | | | | | | | | | | | | | |
| $l$ = 20, Figs. 1626 to 1630 | Solid girders .. .. | 1·40 | 600 | 430 | 1130 | 1180 | 1·90 | 840 | 840 | 1850 | 1930 | 1·50 and 2·30 | 600 | 580 | 1260 | 2680 | 2800 |
| | Multiple lattice-girders | 2·00 | 500 | 430 | 1020 | 1070 | 2·20 | 800 | 840 | 1800 | 1890 | 2·00 and 2·50 | 560 | 570 | 1260 | 2680 | 2750 |
| | Cross lattice-girders .. | 2·00 | 480 | 430 | 1000 | 1050 | 2·20 | 630 | 840 | 1620 | 1690 | 2·00 and 2·50 | 480 | 500 | 1260 | 2460 | 2580 |
| $l$ = 30, idem | Solid girders .. .. | 2·00 | 1040 | 440 | 1630 | 1700 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | Multiple lattice-girders | 2·50 | 900 | 440 | 1540 | 1610 | 2·80 | 1400 | 850 | 2430 | 2590 | 2·50 and 3·00 | 1030 | 950 | 1270 | 3580 | 3740 |
| | Cross lattice-girders .. | 2·50 | 800 | 440 | 1360 | 1430 | 2·80 | 1150 | 850 | 2200 | 2300 | 2·50 and 3·00 | 900 | 850 | 1270 | 3320 | 3470 |
| $l$ = 40, idem | Solid girders .. .. | 4·50 | 1200 | 540 | 1910 | 2000 | 4·60 | 1600 | 990 | 2850 | 2980 | 5·00 | 1200 | 1100 | 1500 | 4180 | 4370 |
| | Cross lattice-girders .. | 4·50 | 900 | 540 | 1580 | 1660 | 4·60 | 1350 | 990 | 2570 | 2690 | 5·00 | 980 | 980 | 1500 | 3810 | 3980 |
| | Arched girders .. .. | 6·50 | 800 | 500 | 1430 | 1500 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| $l$ = 50, idem | Multiple lattice-girders | .. | .. | .. | .. | .. | 5·80 | 2100 | 1000 | 3410 | 3560 | .. | .. | .. | .. | .. | .. |
| | Cross lattice-girders .. | .. | .. | .. | .. | .. | 5·80 | 1740 | 1000 | 3010 | 3150 | 5·80 | 1250 | 1300 | 1500 | 4460 | 4660 |
| | Arched girders .. .. | .. | .. | .. | .. | .. | 8 50 | 1550 | 1000 | 2800 | 2930 | 9·00 | 1100 | 1200 | 1500 | 4180 | 4370 |

See AQUEDUCT. ARCH. DRAWBRIDGE. EMBANKMENTS. MATERIALS OF CONSTRUCTION, *strength of*. OBLIQUE ARCH. PIERS. PONTOON. RETAINING WALLS. VIADUCT. WEIGHBRIDGE.

*Works on Bridges*:—Perronet, 'Œuvres,' folio and 4to, 1788. Gauthey, 'Traité des Ponts,' 3 vols., 4to, 1816. Ware, 'On Vaults and Bridges,' 8vo, 1822. Hann and Hoskin's 'Theory, Practice, and Architecture of Bridges,' 5 vols., royal 8vo, 1843–50. E. Clark, 'On the Britannia and Conway Bridges,' 2 vols., 8vo, plates, folio, 1850. Bow, 'On Bracing,' 8vo, 1851. Boudsot, 'Des Ponts Suspendus,' 4to, Paris, 1853. Humber, 'On Iron Bridges and Girders,' imperial 4to, 1857. Roy, 'Des Ponts et Viaducts en Maçonnerie,' 8vo, 1857. J. H. Latham, 'On the Construction of Iron Bridges,' 8vo, 1858. L. von Klein, 'Sammlung eiserner Brücken constructionen,' Stuttgart, 1863. Humber, 'On Iron Bridge Construction,' 2 vols., imperial 4to, 1864. J. Gaudard, 'De Divers Systèmes de Ponts en Fer,' 8vo, Paris, E. Lacroix, 1865. Haupt's 'Theory of Bridge Construction,' 8vo, New York, 1865. Stoney, 'On Strains in Girders,' 2 vols., royal 8vo, 1866–69. W. Fränkel, 'Berechnung eiserner Bogenbrücken,' Hanover, 1867. Shield's 'Theory of Strains in Girders,' royal 8vo, 1867. Baker, 'On Long-Span Railway Bridges,' 12mo, 1867. Unwin, 'On Wrought-Iron Bridges and Roofs,' 8vo, 1869. J. A. Roebling, 'Long and Short Span Railway Bridges,' folio, Van Nostrand, New York, 1869. Humber, 'Strains in Girders,' 12mo, 1869. Bree's 'Railway Practice,' 4 vols., 4to. Byrne's 'Essential Elements of Practical Mechanics.' Seguin Ainé, 'Des Ponts en Fil de Fer.' Also various Papers in 'Annales des Ponts et Chaussées,' and the 'Transactions Inst. C. E.,' the 'Inst. Mechanical Engineers,' 'Society of Engineers.'

BRIDGE-HEAD. FR., *Tête de pont*; GER., *Brückenkopf*; ITAL., *Testa di ponte, Testata*; SPAN., *Cabeza del puento*.

See FORTIFICATION.

BRITANNIA-METAL. FR., *Métal britannique, Métal anglais* · GER., *Britannia Metall*; ITAL., *Lega Britannia*.

See ALLOYS, p. 49.

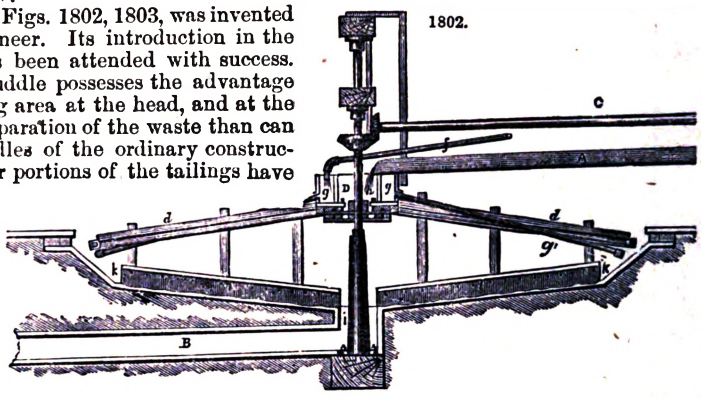
BRONZE. FR., *Bronze*; GER., *Bronze*; ITAL., *Bronzo*, SPAN., *Bronce*.

See ALUMINUM. BRONZE. COPPER. TIN. ZINC.

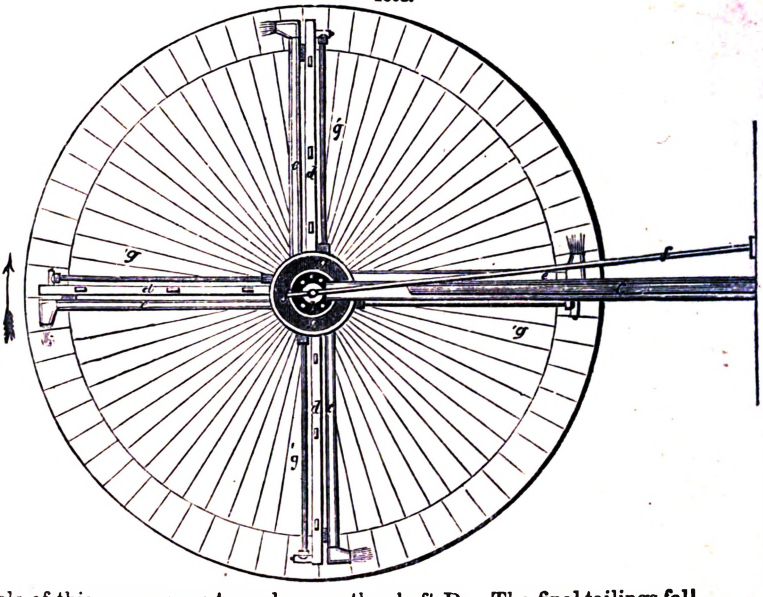
BUDDLE. FR., *Baquet à rincer, lavoir*; GER., *Waschtroj, Waschwerk* · ITAL., *Lavatoio della miniera*; SPAN., *Mesa de lurar*.

The apparatus shown in Figs. 1802, 1803, was invented by Hundt, a Prussian engineer. Its introduction in the gold mines of Victoria has been attended with success. The arrangement of this buddle possesses the advantage of affording a large working area at the head, and at the same time effects a better separation of the waste than can be produced by round buddles of the ordinary construction. And when the lighter portions of the tailings have become separated from the heavier near the periphery of the circle, the area over which they are distributed gradually diminishes, which, by increasing the rapidity of the flow, enables them to be more readily carried off. In Australia this apparatus is employed for concentrating tailings from which a large proportion of gold has been previously extracted by the usual appliances. A is the spout which conducts the mixture of water and sand to the buddle: B, the outlet for carrying off the earthy impurities or final tailings; C, shaft communicating motion to the buddle arms *d*; *e*, distributing *launders*; and *g'*, pipes attached to them. The pipe *f* supplies clean water to the annular cistern *g*, from whence it passes by the pipes *g'*, with rose apertures at the ends, and serves to dilute the mixture of water and tailings discharged by the launders *e*, on the annular incline at the periphery. The whole of this arrangement revolves on the shaft D. The final tailings fall

1802.




1803.



into the circular pit *i*, previous to being carried off by the channel B. To the wooden bars *k* are attached pieces of canvas, which sweep over the surface of the stuff deposited in the buddle, and keep it even and free from ruts. The tailings, entering the receiver *h*, are distributed at the periphery of the buddle through the four launders *e*, which at their extremities are turned at right angles to the direction of their motion when in action; and at the same time clean water is distributed by the apertures pierced in the terminations of the pipes *g'*. The speed given to this arrangement of arms, launders, and pipes, revolving on the shaft D, varies in proportion to the state of divisions of the sands to be treated. When these are rather coarse, the machine may make from six to eight revolutions a minute; but when very fine stuff has to be operated upon, the speed is considerably increased. The influx of tailings and water must be regulated in accordance with the speed of the arms and the density of the material operated upon; and although no very definite instructions can be given with regard to this subject, a chart of the apparatus will enable any intelligent workman to make the necessary adjustments. The bed may be from 12 to 18 ft. in diameter, and it may have an inclination of from 6 to 9 in. from the edge to the centre. At the Port Phillip works the tailings cleaned by machines of this description are subsequently roasted, and passed through Chilian mills; but where, as in California, the enriched pyrites have to be transported to considerable distances, it would require to be more than once passed through the machine, or, after being once buddled, the heads might be further enriched, either in the rocker, or by a hand-buddle or shaking-table. A buddle of this kind can be filled in about four hours, and it will be found an excellent apparatus for enriching ores with but little waste. If it be intended to dress sulphides directly from the *riffles*, so as to render them almost entirely free from siliceous matter, the first heads will require to be re-washed once at least, and the second heads twice; but when this is done, it is necessary to be provided with other buddles besides those which first receive the tailings direct from the riffles, and which will be constantly in use for that purpose.

When the tailings to be washed are not conducted directly from the blanket boards, but are taken either from tyes or the heads of other buddles, they are charged with a shovel into a *hopper* connected with a circular sieve, working in water, which discharges into the spout A.

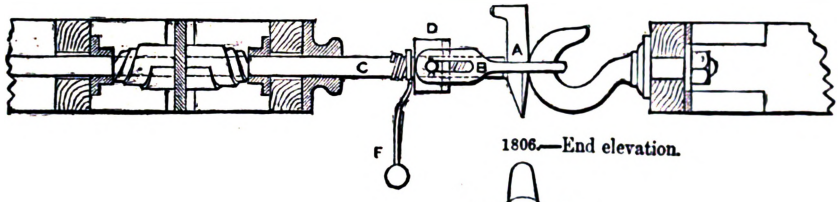
See Gold and Gold Mining.

**BUFFER.** Fr., *Tampon, Appareil de choc;* Ger., *Buffer;* Ital., *Respingente.*

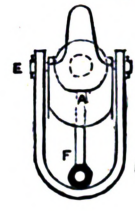
A buffer is a cushion, or apparatus with strong springs, employed to deaden the concussion between a moving body and one, in motion or at rest, on which it strikes, as at the end of a railway carriage. A buffer is sometimes called a *buffing apparatus*, when it is composed of two or more parts or of two or more springy substances, as of steel, india-rubber, gutta-percha.

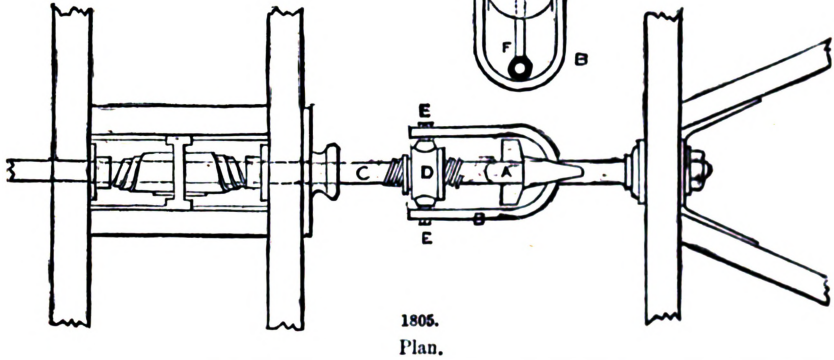
The central buffing and drawing apparatus, designed by E. D. Chattaway. is shown in Figs. 1804 to 1806.

1804.
Side elevation.




1806.—End elevation.




1805.
Plan.

Fig. 1804 is a side elevation, and Fig. 1805 a plan of the new coupling, working in connection with an ordinary draw-hook; and Fig. 1806 is an end view of the buffer-head. The buffer and draw-hook are constructed in one piece, and the buffer-head A, instead of being circular, is made of the peculiar form shown in Fig. 1806. The lower portion only is curvilinear, and the upper part is made narrow, and while presenting a buffing surface in front, it is shaped on its inner side similar to a *draw-hook*, for the purpose of receiving the coupling-link B, which works upon it as upon an ordinary draw-hook, and thus forms a complete hook and link connection. The draw-rod C is screwed near the end just within the buffer-head. Upon this screwed part is fitted the

adjusting nut and collar D with projection arms E, Fig. 1805, carrying the large coupling-link B. The coupling can thus be drawn hard up or slackened off by means of the pendulous lever F.

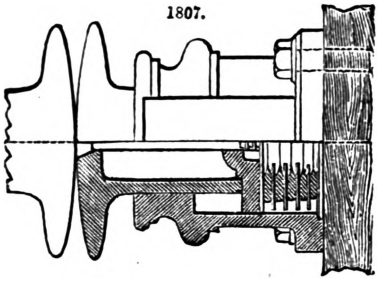
The ordinary coupling and buffing arrangements as applied to railway wagons are open to several objections. As there is no means of tightening up the couplings, there is always a considerable amount of play between the adjacent vehicles of a train, frequently as much as 18 in. with wagons. The effect of this is, in the first place, to lengthen the train, thereby causing a greater expenditure of motive power, owing to increased effect of the wind and pressure of the flanges of the wheels against the rails, when the train is running through sharp curves; and, in the second place, to render the couplings liable to break or to become detached from the draw-hooks, in consequence of the train being started and stopped in detail by a series of sudden and violent jerks: a jerking action also causes a severe strain upon the draw-springs and often breaks them; besides, it acts injuriously upon the permanent way, and increases the risk of conveying goods of a fragile nature. As regards corner buffers, they are objectionable from the circumstance of the two buffers being seldom struck at the same instant or with the same degree of force, even on a perfectly straight line; while on curves the buffing action is mainly confined to one side of the train, severely straining the framing of the vehicles, and having a tendency to force the tenons out of the mortices. Besides tending to damage the rolling-stock, this action also tends to injure the permanent way, and to increase the cost of maintenance of both. It is also to be remarked that the ordinary buffers and couplings are always opposed to instead of being in harmony with each other, the couplings being slackened as the buffers are brought into play, and *vice versâ*; and the reaction of the buffers has sometimes fractured the couplings.

A further objection to the ordinary couplings is the difficulty and delay frequently experienced in attaching and detaching wagons, since, unless the couplings be slack, it requires a violent shunting together of the train to allow the coupling-link to be slipped over the draw-hook; and if the draw-hooks be close to each other before the coupling has been lifted up, the train has to be drawn apart to admit of the link being raised, and then shunted together again in order to be attached. Independent of extra expenditure of engine-power and wear and tear of rolling-stock, this shunting is also a source of accident.

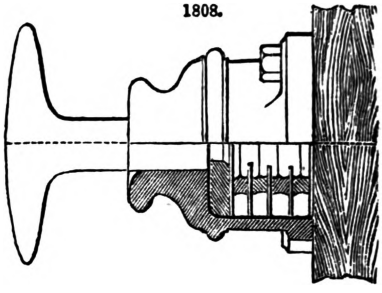
The most complete and effective buffing apparatus now in use is that of L. Sterne, shown in Figs. 1807 to 1811.

The buffers or springs, Figs. 1807, 1808, are built up of soft india-rubber rings and circular steel plates; the terminal plates of each of the springs being complete discs, some are formed with a hole through the centre. During the process of vulcanization the buffer-rings become inseparably united with the plates, and each spring thus becomes a perfectly air-tight chamber. When the pressure is brought to bear on the springs, the air within them becomes compressed, and offers a resistance proportionate to the amount of such compression and to the area of the discs upon which the

1807.



1808.



pressure of the air is exerted. The india-rubber rings not only perform the office of securely retaining the air within them, but they completely resist sudden concussions.

In order to avoid friction upon the rubber, by which it would be quickly destroyed, the circular plates are extended beyond the rings to a distance proportioned to the depth of these rubber rings. The india-rubber, therefore, cannot be injured, or come in contact with the inner surface of the cylindrical cover.

These buffers can be made of any desirable form, and air-tight chambers, constructed in the manner just described, can be built up to any length required in practice. It will be seen that no mechanical fittings are required to make a perfectly air-tight chamber. The union of the rubber to the metal being of a solid and not merely adhesive character, the juncture is impervious.

These buffers are capable of resisting great compressive force, while at the same time they possess great sensitiveness as springs. Unlike a steel spring, which, if made to resist great force, is rigid until a considerable weight is brought to bear upon it, this buffer-spring is sensitive to a very slight pressure, and yet absorbs a power of 15 tons, being 100 per cent. more than the resisting power of any steel springs used for this purpose. In most cases, where the action of buffers is required, the apparatus of Sterne, without alteration of principle, may be applied.

1809.

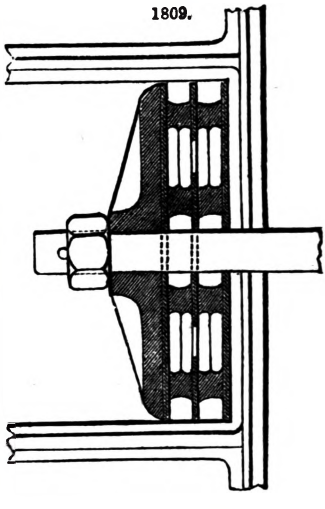


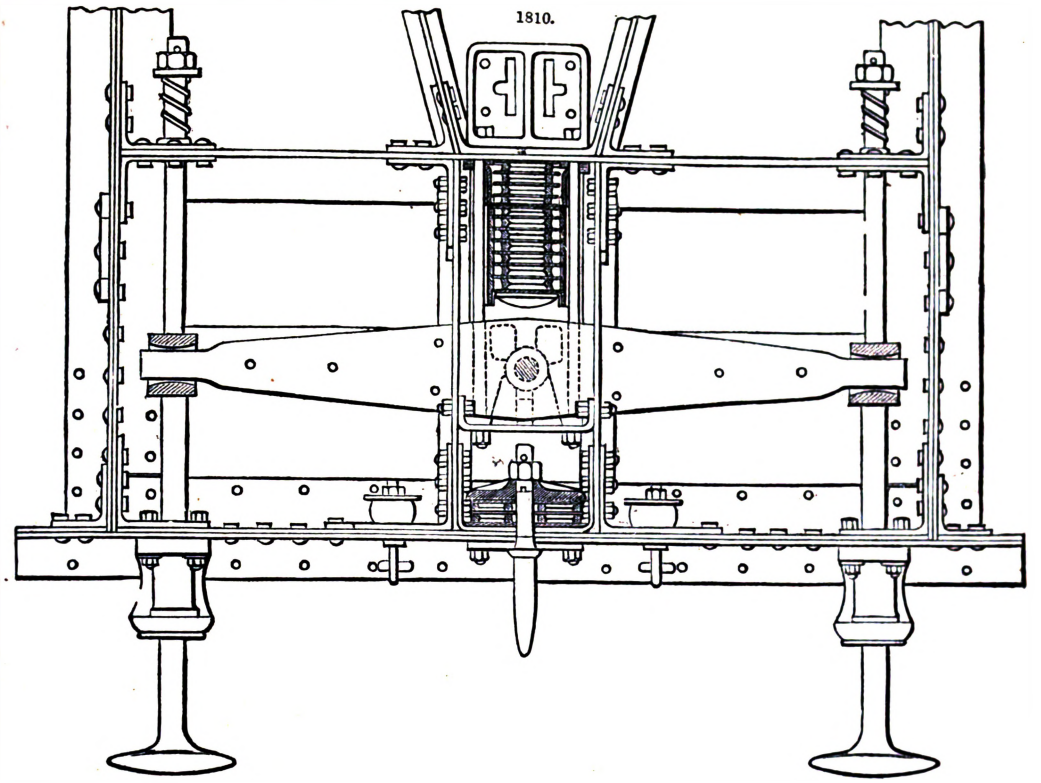
Fig. 1807 shows a cast-iron case, with a solid wrought-iron plunger, four rubber rings, and five steel plates.

Fig. 1808 is of a cast-iron case, containing a cast-iron cylinder-plunger, pneumatic spring power, five rubber rings, and six steel plates.

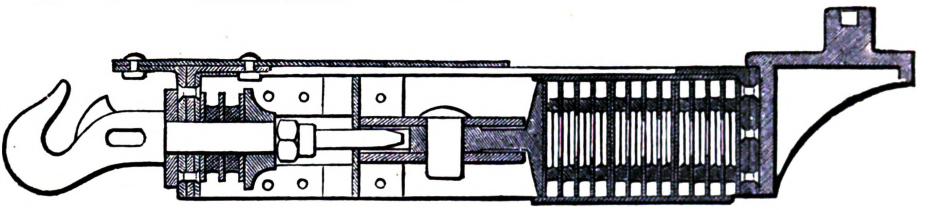
Fig. 1809 represents a pneumatic rubber draw-spring. It has four rubber rings and three oval steel plates.

Sterne's buffer is in use on many railways. The arrangement, Fig. 1810, is that adapted to the carriages of the Metropolitan Railway.

1810.



1811.



Each buffer-rod carries a kind of shoe embracing the ends of a compensating travelling beam, which extends from one spindle to the other. This transmits the pressure fairly to the springs, at the same time enabling the buffer-rods to accommodate themselves freely to the position of the carriages passing round curves. The buffing spring occupies a length of 13½ in. when uncompressed, and is capable of being compressed 9 in. The light spiral springs at the end of the buffer-spindles are merely placed there to prevent chattering. The draw-spring is formed by a pair of pneumatic springs composed of four rings of rubber each, inseparably united to three oval steel plates through which the draw-bar, Figs. 1810, 1811, passes. See LOCOMOTIVES.

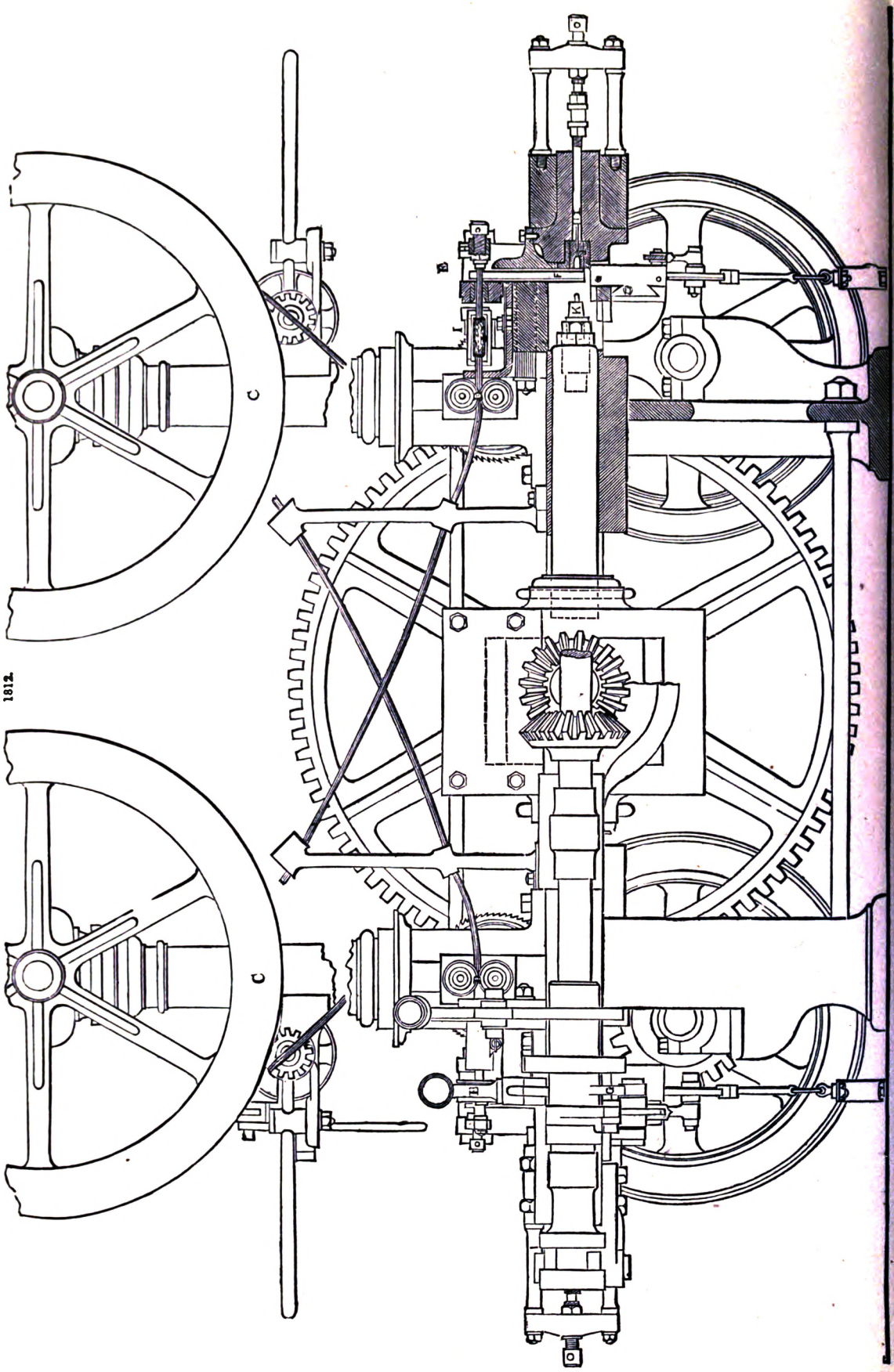
BUILDING. FR., *Construction, bâtiment;* GER., *Bauen;* ITAL., *Costruzione.*

See BOND. BRIDGE. FOUNDATIONS. JOINTS. MASONRY. RAILWAY ENGINEERING. ROOFS. SCAFFOLDING.

BULLET-MAKING MACHINE. FR., *Machine à faire des balles;* GER., *Kugel-Giessmachine.*

In the manufacture of ordinary bullets for small arms the lead is first melted in an ordinary cast-iron vessel, fitted with a spout and movable plug at the bottom. By means of a removable spout, the liquid lead is conveyed to the cylinder A in Fig. 1813, where it remains until it is a solid, but not any longer, as the nearer it is to the fluid state, the easier it is shaped, so as to form a rod. The lead, being pushed up by hydraulic pressure, as in the lead-pipe machine of Cornell, flows out at the orifice in the die B, which may be made with different shaped orifices.

To convert the rod into bullets, it has first to be cut into portions, then each portion has to be compressed in ventilated dies, care being taken to prevent metallic contact, which is done by lubrication.


1812.
C
C

Such conditions may be attained by a great variety of mechanical arrangements: Figs. 1811, 1814, illustrate John Anderson's Bullet-making Machine, which was extensively employed at Woolwich.

By referring to Fig. 1812, it may be seen that the rod of lead from the lead-pipe or lead-rod machine, after being coiled upon a portable reel, is wound upon the reels C, C, which are fixed upon the framing of the bullet machine, Fig. 1812.

The lead rod is then conducted by a pair of small rollers D, through the cutting-off lever E, into the clips F, Fig. 1814, in which it is gripped while being sheared off; when the lever is raised up to perform this operation by the cam (G Fig. 1812) the length of lead rod thus cut off is determined by the adjustable stop.

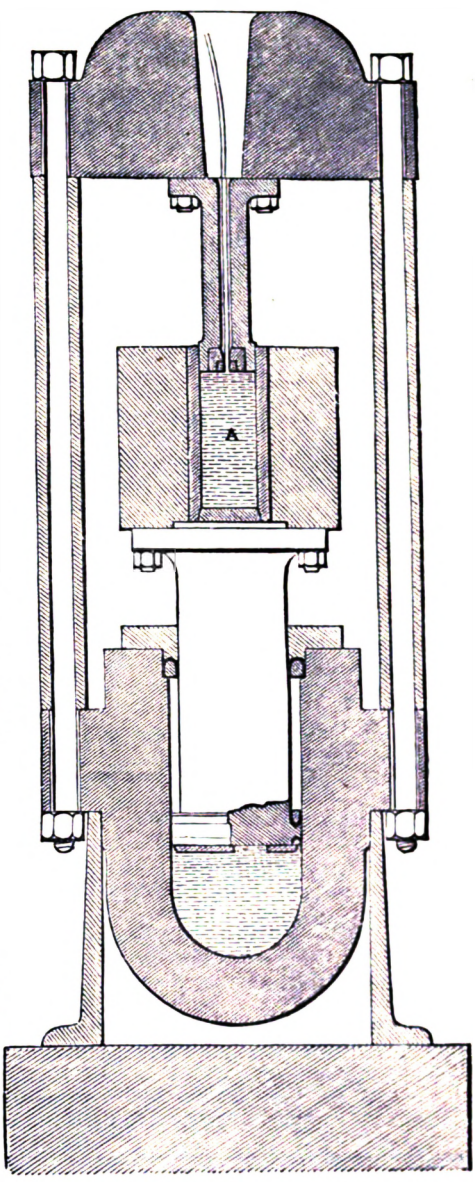
To prevent the lead rod from slipping out of the die, it must be thoroughly clean and free from grease; it is therefore passed through a roll of tow or cotton waste I saturated with turpentine.

After the block of lead of the required length is cut off, the clips E, F, Figs. 1812, 1814, are opened, and the block is allowed to fall by gravitation to the bottom of the clips, and from thence is pushed into the forming-die J, Fig. 1812, by the punch K (the point of which is lubricated at each stroke); the finished bullet is then knocked out by the small punch L, into a shoot, by which it is conveyed to suitable boxes.

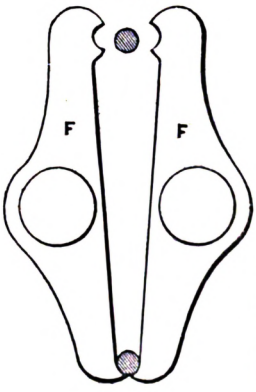
In order to ensure a clean and perfectly-formed bullet, it is necessary to ventilate the die; in this case the air escapes through the small punch L, which is bored out for that purpose.

When the portion of lead within the die has been compressed, the superfluous metal is squeezed out at the junction, thus forming a sort of frill, to remove which clips, Figs. 1812, 1814, are employed. These clips are pieces of steel containing a hole the size of the bullet; they rise in front of the die so soon as the punch has retired; at the next instant the bullet is pushed through the hole, thus leaving the frill behind.

1813.

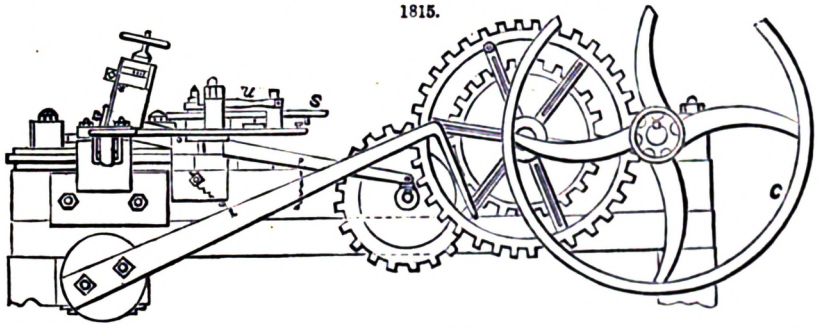



1814.




When indentures have to be given to bullets, this is accomplished by passing them between a revolving disc and a corresponding fixed segment, the acting surfaces being of the required shape, and so placed with regard to each other that the entrance of the indenting channel shall be wider than the opening at the point of exit. The revolving surface imparts a circular motion to the bullets, in a manner similar to that of milling coin.

1815.




J. D. Custar's Bullet Machine, Fig. 1815, has an arrangement of devices for cutting off the blank from a rod or thick wire, and depositing it in a radial groove *u* in the flat face of a turn-

table which carries it in front of a cylindrical die. A piston or male die fitting the said cylinder forces the blank therein and against a female die. When the male die is retracted, and the female die thrust forward, it forces the blank out of the cylinder and upon the carrier S, which during the operation of the dies remains at rest. The bullet is then carried around the lathe, where it is again seized between the sliding mandrel and centre of the lathe, and trimmed off to the proper shape by a tool which is fed to the work by means of a lever operated by a cam attached to the driving machinery C.

BUNG-CUTTING MACHINE. Fr., *Machine à couper le tampon de bois;* Ger., *Spundzapfen-Schneidmaschine;* Ital., *Macchina da cocchiumi.*

See Cask-making Machinery.

BUOY. Fr., *Bouée, Amarque, Balise;* Ger., *Buje, Boje, Ankerboje;* Ital., *Gavitello;* Span., *Boya.*

See Lighthouses; Beacons; and Buoys.

BURNISHER. Fr., *Brunissoir;* Ger., *Polirstahl;* Ital., *Brunitoio.*

See Hand-Tools.

BUSH. Fr., *Coussinet;* Ger., *Metallfutter;* Ital., *Bronzina;* Span., *Coginete.*

A bush is a perforated piece of metal, as hard brass, let into certain parts of machinery, to receive the wear of pivots, journals, and the like, as in the pivot-holes of a clock, the hub of a cart-wheel, and so on. Any similar lining of a hole with metal, as the vent of a gun, is termed the *bush.* See Details of Engines; Ordnance; and Small Arms.

BUTTERFLY-VALVE. Fr., *Robinet papillon;* Ger., *Schmetterlings-Ventil;* Ital., *Valvola a farfalla.*

See Valves.

BUTTRESS. Fr., *Contre-fort, éperon, arc boutant;* Ger., *Strebepfeiler;* Ital., *Contraforte;* Span., *Ó machon.*

A buttress is a projecting support to the exterior of a wall, most commonly applied to churches in the Gothic style, but also to other buildings, and sometimes to mere walls. A prop, a shore, or support, is also called a buttress. See Coast Defences. Construction. Fortification.

BUTT-WELD. Fr., *Soudure par rapprochement;* Ger., *Stumpfe Schweissfuge;* Ital., *Bollitura affrontata.*

See Forging.

CABLE. Fr., *Câble;* Ger., *Tau;* Ital., *Canapo, Cavo;* Span., *Cable.*

A cable is a large, strong rope or chain, employed to retain a vessel at *anchor*, and for other purposes. It is commonly made of hemp or iron, but sometimes of iron or copper wire, as in the case of the cable of a *suspension bridge*, or of a submarine connection in the electrical *telegraph.* Practical information, however limited, upon the strength of *rope* and *chain*, is of great value and importance to the seaman, since there is scarcely an operation connected with his duties that can be performed without the use of a chain or a rope.

William Macdonald, Superintendent of the Liverpool Chain-testing Works, in 1860, before a committee of the House of Commons, gave the following tabulated statements, which show the total number of fathoms of chain proved by him from 1855 to 1859.

Stud Chain.

| Date. | Total Number of Fathoms proved. | Number of Fathoms defective. | Number of Fathoms not defective. | Number of Fathoms condemned. | Percentage of defective Chains. |
|---|---|---|---|---|---|
| 1855 .. .. .. .. .. .. | 10717 | 8862 | 1855 | 576 | 82¾ |
| 1856 .. .. .. .. .. .. | 11336 | 9575 | 1761 | 438 | 84½ |
| 1857 .. .. .. .. .. .. | 12826 | 10393 | 2433 | 316 | 81 |
| 1858 .. .. .. .. .. .. | 9387 | 8278 | 1109 | 383 | 88 |
| 1859 (to August 2nd) .. .. | 5711 | 4038 | 1673 | 329 | 71 |
| Total .. .. | 49977 | 41146 | 8831 | 2042 | 82¼ |

Close Link.

| Date. | Total Number of Fathoms proved. | Number of Fathoms defective. | Number of Fathoms not defective. | Number of Fathoms condemned. | Percentage of defective Chains. |
|---|---|---|---|---|---|
| 1855 .. .. .. .. .. .. | 3799 | 1918 | 1881 | 278 | 50½ |
| 1856 .. .. .. .. .. .. | 8752 | 4636 | 4116 | 37 | 52¾ |
| 1857 .. .. .. .. .. .. | 10190 | 7398 | 2792 | 955 | 72 |
| 1858 .. .. .. .. .. .. | 8731 | 5469 | 3262 | 44 | 62½ |
| 1859 (to August 2nd) .. .. | 5412 | 2066 | 3346 | 227 | 38 |
| Total .. .. | 36884 | 21487 | 15397 | 1541 | 58½ |

Deductions and rules respecting the strength of materials, based on the experiments of Tredgold, Barlow, Fairbairn, and Hodgkinson, are not reliable, for these and other experimentalists

employed incomplete testing apparatus; and in general they operated upon fragments of materials too small to warrant their conclusions with regard to large and complicated structures. This remark does not apply to David Kirkaldy, who, from his skill and the accuracy and great range of his testing machinery, furnishes results in every respect reliable. We add a tabulated statement respecting the relative strength of welded joints, taken from Kirkaldy's work, 'Results of an Experimental Inquiry into the Tensile Strength and other Properties of various kinds of Wrought Iron and Steel.'

In the experiments made by Kirkaldy to ascertain the strength of welded joints, the pieces were cut through the middle, and then scarfed and welded in the ordinary manner by the same smith who prepared the bolts for his other experiments, and a few were prepared by a chain-maker, for comparison. The results varied greatly,—fourteen, operated on by the smith, show a loss, compared with the original whole bar, from 4·1 to 43·8 per cent., the mean loss being 20·8 per cent.; four by the chain-maker, from 2·6 to 37·4; mean, 15·1 per cent. Of the former, four broke solid, away from the weld: eight, partly through solid portion and partly at the weld; two separated at the weld. Of the latter, two broke solid; one broke partly solid and partly at the weld; and one gave way at the weld. It may be noticed that different sizes and also different qualities were used, but the results were alike uncertain, and are further proof of the correctness of the following observations by James Nasmyth, which appeared in 'The Engineer,' 8th March, 1861, a considerable time after the experiments of Kirkaldy were made:—

"Of all the processes connected with the working of malleable iron there is none that has a more intimate relation to the security of life and property than that of *welding*, or the process by which we are enabled to unite together, in one mass, the several portions of malleable iron, of which the generality of works in that material are formed. Every single link in a chain cable, every wheel-tire in a railway train, directly owes its trustworthiness to the manner in which the process of welding has been performed, in so far as that any imperfection in any one single member of the set of cable links or railway wheel-tires may involve a most fearful loss of life, of which, of late years especially, we have had such distressing and melancholy experience.

"In order to render clear the following remarks as to the cause of, and means that should be employed to prevent, defective welding, it is necessary to explain the nature of the process of welding, which consists in inducing upon malleable iron, by means of a very high heat, a certain degree of adhesiveness, so that any two pieces of malleable iron, when heated to the requisite degree, will, if brought into close contact, adhere or stick together with a greater or less tenacity, according to the amount of force applied to urge them into close contact. . . . .

"It is, therefore, to the means of thoroughly expelling this vitrified oxide from between the surfaces of the iron where the welded junction is to take place that we must direct our attention; for so long as any portion of this adhesive viscid substance is permitted to exist and interpose itself between the surfaces we desire to unite, no sound junction can take place, and once it has made a lodgment no after-heating or hammering, be it ever so severe, will cause its thorough expulsion. It is, therefore, to the thorough expulsion of the vitreous oxide in the first stage of the welding that we must direct the most careful attention; and it would, in no small degree, tend to prevent those fearful accidents of which defectively-welded ironwork is the principal cause.

"Since the chief cause of defective welding arises from portions of the vitreous oxide of the iron being shut up between the surfaces at the part presumed to have been welded, and that, besides the impossibility of ascertaining, in the majority of cases, after the process of welding has been gone through, whether or not this vitreous oxide has been thoroughly expelled, and the surfaces at the welding brought into perfect metallic union, and that no after-heating or hammering can dislodge the vitreous oxide when once it has effected a lodgment, our best security is to form the surfaces of the iron at the part where the welding is desired to take place, so that when applied to each other, at the welding heat, *their first contact with each other shall be in the centre of each.*"

Kirkaldy tested two steel bars welded at the makers' works, the result still more unsatisfactory than with iron—one showing a loss of 45·0, the other 59·6 per cent.; whilst other two parted at the weld during the operation of forming the heads, previous to testing. At the commencement of these experiments several attempts were made to form heads on the steel specimens, in the same manner as on the iron, by welding on rings; but as they either failed at the weld, or the steel was found to be burned, that method was abandoned.

With the view of ascertaining the effect of heating iron to the welding point, and then allowing it to cool slowly without being hammered, an experiment was made by Kirkaldy with a bar of Glasgow B. Best, the results of which are stated in his table N, 1095. Although its breaking strain was nearly the same as that borne by another piece, 1094, off the same bar, in the ordinary condition, yet it will be found that the ductility of the iron had been injured by the high temperature and want of hammering; for it was found that instead of 42·2 per cent. it only contracted 27·8, or 34 per cent. less than the latter.

Figs. 1816 to 1829 exhibit mooring and other chains, with the articles required to be appended to such chains, and the proportions of iron chain cables, as supplied to the English Royal Navy.

Fig. 1816 shows the pin and lead pellet, through forelock, and part of the ring or shackle on the anchor-shank. Figs. 1816 to 1821 present two views of each part of a cable where connections are made.

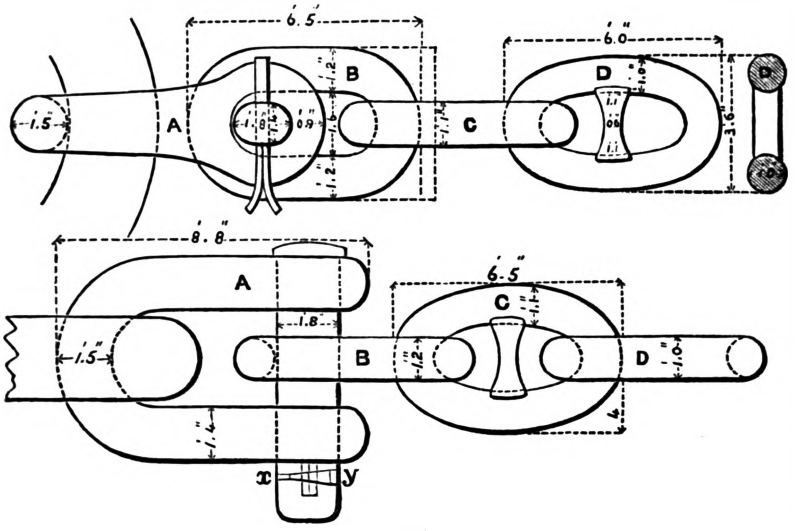
The dimensions given on the links, &c., signify so many diameters of the iron of the common links of the cable, thus forming the scale for all sizes. In the mooring chains and gear, the unit is the thickness of the iron of the link.

Referring to Figs. 1816 to 1821, and large shackle for connecting any length of cable of 12½ fathoms: B, end links, without stay-pins; C, enlarged links, with stay-pins; D, common links, hickness put = 1; E, swivel in the middle of every other length of 12½ fathoms; F, joining hackle for connecting either end of any length with any other length of the same size.

WELDED

| Index No. | Names of Makers or Works, and how Treated. | Original Diam. | Original Area. | Weight on Steel-yard. | Breaking Strain. Total on Specimens. | | Breaking Strain. Welded. | |
|---|---|---|---|---|---|---|---|---|
| | Iron Bars. | in. | sq. in. | lbs. | lbs. | | lbs. | |
| 1491 | Govan B. Best. Welded by smith | ·76 | ·4536 | 590 | 25590 | 22797 | 56415 | 50963 |
| 1492 | " " " " | ·76 | ·4536 | 569 | 25002 | | 55119 | |
| 1493 | " " " " | ·75 | ·4417 | 407 | 20466 | | 46335 | |
| 1494 | " " " " | ·76 | ·4536 | 421 | 20858 | | 45983 | |
| 1495 | Govan Ex. B. Best. Welded by chain-maker .. .. .. .. | ·76 | ·4536 | 605 | 26010 | 21411 | 57341 | 48984 |
| 1496 | " " " " | ·76 | ·4536 | 598 | 25814 | | 56909 | |
| 1497 | " " " " | ·76 | ·4536 | 420 | 20830 | | 45921 | |
| 1498 | " " " " | ·68 | ·3632 | 140 | 12990 | | 35765 | |

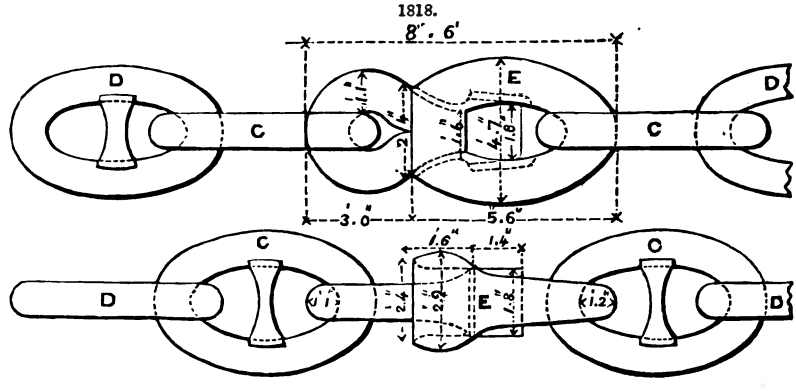
1816.




1817.

$x\,y$ = pin and lead pellet through the bolt and forelock.

1818.




1819.

Figs. 1822, 1823, George Elliott's splicing shackle.

Figs. 1824, 1825, Hardy's mooring swivel; 1826, splicing tails; 1827, 1828, swivel and shackle for mooring chain; and 1829, links for pendant, or bridle chains.

Before 1842 no positive information on the strength of hempen cables was established. However, some experiments on the smaller kinds had been made, and the strength of a good 10½-in.

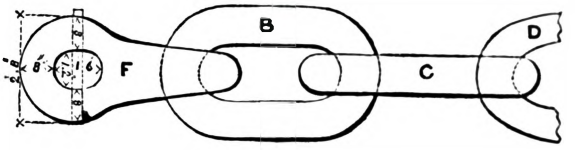
JOINTS.

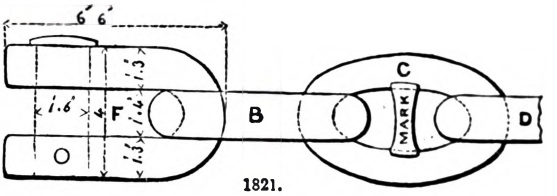
| Breaking Strain the Square Inch, Unwelded. | | Difference between Welded and Unwelded Bars. | | | Equivalent. | Elongation. | | | Fracture. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Diameter of a Bar Unwelded. | Original Length of Stretched part in Column*. | | | Crys. | Where. |
| lbs. | | lbs. | | per cent. | in. | in. | in. | per cent. | | |
| 61106 | 59548 | 4691 | 8585 | 7·7 | 0·701 | ·80 | ·47 | 5·9 | 0 | Solid. |
| 59316 | | 4197 | | 7·1 | | ·68 | | | 1 | Solid. |
| 58886 | | 12551 | | 21·3 14·5 | | ·18 | | | 18 | Solid and weld. |
| 58884 | | 12901 | | 21·9 | | ·20 | | | 65 | Solid and weld. |
| 59070 | 57591 | 1729 | 8607 | 2·9 | 0·683 | 1·25 | ·84 | 10·5 | 0 | Solid. |
| 58452 | | 1543 | | 2·6 15·1 | | 1·26 | | | 0 | Solid. |
| 55653 | | 9732 | | 17·5 | | 0·46 | | | 45 | Solid and weld. |
| 57190 | | 21425 | | 37·4 | | 0·08 | | | 0 | Weld. |

cable or 10-in. hawser-laid rope was considered to be about 20 tons; these formed a scale by which the strength of other sizes was calculated, but there was no satisfactory evidence in proof of this scale with regard to any size. It was therefore ordered that a series of experiments should be made in Woolwich Dockyard to ascertain by positive proof the strength of all cables, both hempen and chain, of various sizes, from the smaller kind up to the largest then in use. The experiments were accurately recorded by Nicholas Tinmouth; but the testing machine used by Tinmouth was far inferior to the one employed at present by David Kirkaldy. The sizes of hemp selected for experiment, Table I., were 25 in. circumference, 22½ in., 20 in., and so on. The sizes of the chain cables were, as shown in Table II., from 2⅛ to ⅝ of an inch.

It is necessary to state that the 2⅛-in. chain was not tested, on account of the probability that the testing machine would be seriously injured in the event of this chain breaking under a heavy strain. There were six experiments upon each of the other nine sizes of chain cable, amounting in the whole to fifty-four; and eight experiments upon each of the nine hemp cables, making together seventy-two.

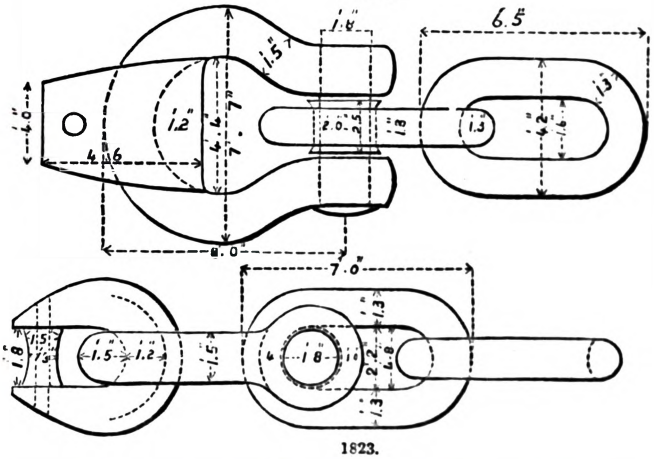
1820.




1821.

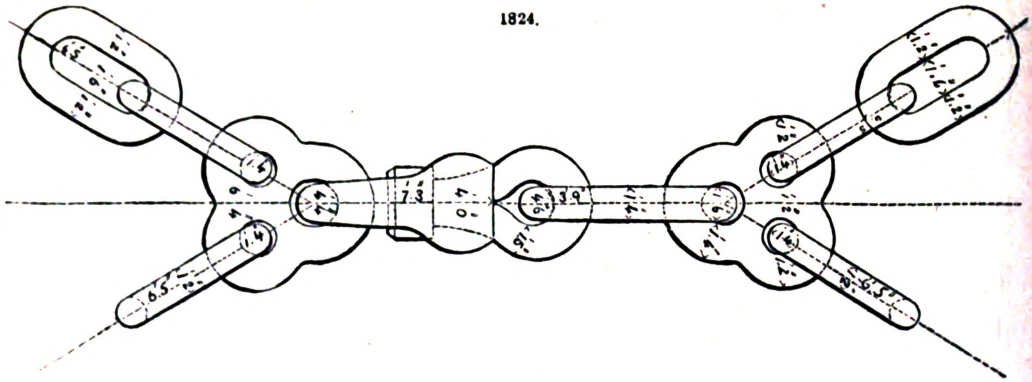
1822.



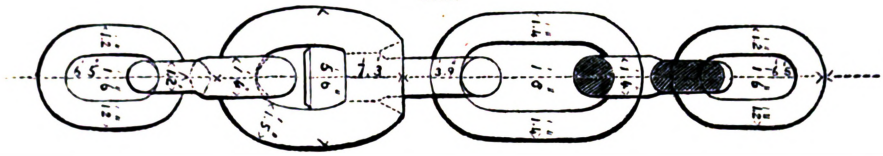
1823.

These experiments are casily distinguished in the Table by their extending through all the columns from side to side. The strength of all the intermediate sizes, both of hemp and chain, was calculated by the following rule:—Divide the difference of the two strains by the difference of the squares of the diameters, or circumference, for a constant multiplier. This multiplier into the difference of the squares of any two sizes will give the number of tons to be added to the strain upon the smaller. As the actual strength of any instrument can only, as a whole, be considered equal to its weakest part, the minimum column of strength in the Tables must be considered the safest. The right-hand column has been calculated from the weakest of all the experiments, and may be serviceable where risk is apprehended and great caution necessary. With reference to the strength of the hawser-laid rope, and rigging or crane chain, in Tables III. and IV., the experiments were made at various times for isolated purposes: and although not in the same progressive order as in the case of the cables, yet the strength was ascertained by the same machine with the same degree of accuracy and embracing a sufficiently numerous class of sizes to render the calculation of all intermediate kinds equally correct.

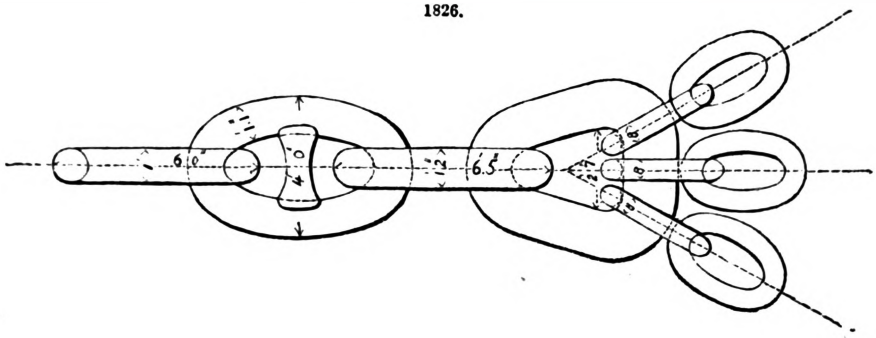
1824.



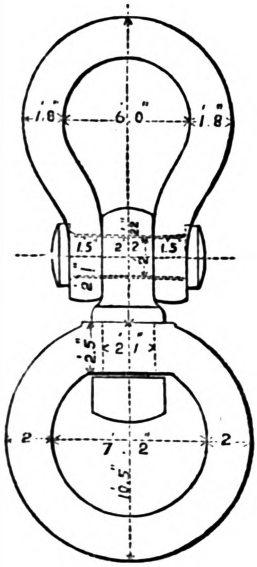
1825.



1826.



1827.



1828.

1829.

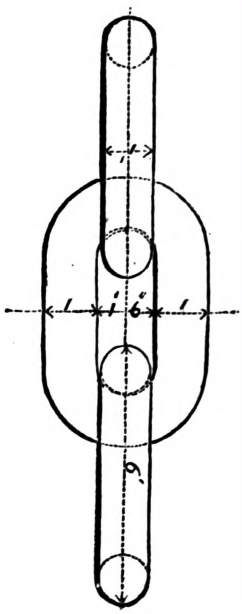


TABLE I.—FOR ASCERTAINING THE STRENGTH OF CHAIN CABLES.

| Size. | No. of Yarns. | Weight, 100 Fathoms. | Breaking Weight, in Tons. | | | | | | | Mean. | Calculated from weakest. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Maximum. | Intermediate Strains. | | | | | Minimum. | | |
| in. | | lbs | | | | | | | | | |
| 26 | 3528 | 14112 | 122·2 | .. | .. | .. | .. | .. | 105·9 | 111·6 | 101·5 |
| 25½ | 3393 | 13572 | 117·5 | .. | .. | .. | .. | .. | 101·9 | 107·3 | 97·6 |
| †25 | 3267 | 13068 | 113· | 107· | 106·5 | 102· | 101·5 | 99· | 98· | 103·2 | 93·8 |
| 24½ | 3122 | 12488 | 114·4 | .. | .. | .. | .. | .. | 94·4 | 102·5 | 90·1 |
| 24 | 3006 | 12024 | 115·7 | .. | .. | .. | .. | .. | 91· | 101·9 | 86·5 |
| 23½ | 2880 | 11520 | 117· | .. | .. | .. | .. | .. | 87·6 | 101·3 | 82·9 |
| 23 | 2763 | 11052 | 118·3 | .. | .. | .. | .. | .. | 84·2 | 100·7 | 79·4 |
| †22½ | 2646 | 10584 | 119·5 | 109·5 | 101·7 | 99·5 | 99· | 96·5 | 94· | 81· | 100·1 |
| 22 | 2529 | 10116 | 111·4 | .. | .. | .. | .. | .. | .. | 77·9 | 95· |
| 21½ | 2412 | 9648 | 103·5 | .. | .. | .. | .. | .. | .. | 74·9 | 90·1 |
| 21 | 2304 | 9216 | 95·8 | .. | .. | .. | .. | .. | .. | 72· | 85·3 |
| 20½ | 2196 | 8784 | 88·3 | .. | .. | .. | .. | .. | .. | 69·2 | 80·6 |
| †20 | 2088 | 8352 | 81· | 78·5 | 78·2 | 78· | 77· | 75·5 | 74·2 | 66·5 | 76·1 |
| 19½ | 1980 | 7920 | 76·7 | .. | .. | .. | .. | .. | .. | 62·1 | 71·3 |
| 19 | 1881 | 7524 | 72·6 | .. | .. | .. | .. | .. | .. | 57·9 | 66·6 |
| 18½ | 1782 | 7128 | 68·6 | .. | .. | .. | .. | .. | .. | 53·8 | 62·1 |
| 18 | 1692 | 6768 | 64·7 | .. | .. | .. | .. | .. | .. | 49·8 | 57·7 |
| †17½ | 1597 | 6388 | 61· | 59·7 | 54·7 | 54·5 | 52· | 50· | 49·2 | 46·* | 53·4 |
| 17 | 1512 | 6048 | 57·3 | .. | .. | .. | .. | .. | .. | 44·9 | 51· |
| 16½ | 1422 | 5688 | 53·9 | .. | .. | .. | .. | .. | .. | 43·8 | 48·7 |
| 16 | 1332 | 5328 | 50·5 | .. | .. | .. | .. | .. | .. | 42·8 | 46·5 |
| 15½ | 1251 | 5004 | 47·3 | .. | .. | .. | .. | .. | .. | 41·9 | 44·3 |
| †15 | 1179 | 4716 | 44·2 | 43· | 42·7 | 42·5 | 42· | 41·7 | 41·5 | 41· | 42·3 |
| 14½ | 1098 | 4392 | 41·6 | .. | .. | .. | .. | .. | .. | 38·4 | 39·9 |
| 14 | 1026 | 4104 | 39·1 | .. | .. | .. | .. | .. | .. | 36· | 37·6 |
| 13½ | 954 | 3816 | 36·7 | .. | .. | .. | .. | .. | .. | 33·6 | 35·4 |
| 13 | 882 | 3528 | 34·4 | .. | .. | .. | .. | .. | .. | 31·3 | 33·3 |
| †12½ | 810 | 3240 | 32·2 | 32·2 | 32· | 32· | 31·2 | 31·2 | 31· | 29·2 | 31·3 |
| 12 | 756 | 3024 | 29·8 | .. | .. | .. | .. | .. | .. | 26·6 | 28·6 |
| 11½ | 693 | 2772 | 27·6 | .. | .. | .. | .. | .. | .. | 24·2 | 26·1 |
| 11 | 630 | 2520 | 25·5 | .. | .. | .. | .. | .. | .. | 21·8 | 23·7 |
| 10½ | 576 | 2304 | 23·4 | .. | .. | .. | .. | .. | .. | 19·6 | 21·4 |
| †10 | 522 | 2088 | 21·5 | 21· | 19·7 | 17·7 | 17·7 | .. | .. | 17·5 | 19·2 |
| 9½ | 468 | 1872 | 19· | .. | .. | .. | .. | .. | .. | 15·7 | 17·1 |
| 9 | 432 | 1728 | 16·7 | .. | .. | .. | .. | .. | .. | 14· | 15·2 |
| 8½ | 396 | 1584 | 14·6 | .. | .. | .. | .. | .. | .. | 12·4 | 13·4 |
| 8 | 315 | 1260 | 12·6 | .. | .. | .. | .. | .. | .. | 10·9 | 11·7 |
| †7½ | 288 | 1152 | 10·7 | 10·5 | 10·5 | 10·3 | 10·3 | 10·3 | 10· | 9·5 | 10·2 |
| 7 | 252 | 1008 | 9·3 | .. | .. | .. | .. | .. | .. | 8·2 | 8·8 |
| 6½ | 216 | 864 | 8·1 | .. | .. | .. | .. | .. | .. | 7· | 7·5 |
| 6 | 189 | 756 | 7· | .. | .. | .. | .. | .. | .. | 5·8 | 6·3 |
| 5½ | 162 | 648 | 5·9 | .. | .. | .. | .. | .. | .. | 4·8 | 5·3 |
| †5 | 135 | 540 | 5· | 4·9 | 4·6 | 4·2 | 4· | 4· | 4· | 3·9 | 4·3 |
| 4½ | 108 | 432 | 4· | .. | .. | .. | .. | .. | .. | 3·1 | 3·4 |
| 4 | 90 | 360 | 3·2 | .. | .. | .. | .. | .. | .. | 2·5 | 2·7 |
| 3½ | 69 | 276 | 2·4 | .. | .. | .. | .. | .. | .. | 1·9 | 2·1 |
| 3 | 54 | 216 | 1·8 | .. | .. | .. | .. | .. | .. | 1·4 | 1·5 |

The lines marked (†) contain the results given by experiments, and the intermediate lines those found by calculation.

TABLE II.—FOR ASCERTAINING THE STRENGTH OF CHAIN CABLE.

| Size. | Testing Strain, in Tons. | Weight, 100 Fathoms. | Breaking Strain, in Tons. | | | | | | Mean. | Calculated from * weakest. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Maximum. | Intermediate Strains. | | | | Minimum. | | |
| in. | | lbs. | | | | | | | | |
| 2¼ | 91½ | 27216 | 130·3 | .. | .. | .. | .. | 121·8 | 125·9 | 107·4 |
| 2⅛ | 81½ | 24276 | 116·2 | .. | .. | .. | .. | 108·6 | 112·3 | 95·8 |
| †2 | 72 | 21504 | 103· | 102·5 | 101· | 97·5 | 97· | 96·25 | 99·5 | .. |
| †1⅞ | 63½ | 18900 | 99· | 97·75 | 93·5 | 90· | 89· | 88· | 92·8 | .. |
| †1¾ | 55½ | 16464 | 85·25 | 81·5 | 80·5 | 67· | 65·5 | 65· | 74·1 | 65· |
| 1⅝ | 47½ | 14196 | 75· | .. | .. | .. | .. | 59·5 | 66·5 | 56· |
| †1½ | 40½ | 12096 | 65·5 | 65·5 | 59·25 | 57·75 | 55· | 54·5 | 59·5 | .. |
| 1⅜ | 34 | 10164 | 53·6 | .. | .. | .. | .. | 44·4 | 48·5 | 40·1 |
| 1¼ | 28½ | 8400 | 42·8 | .. | .. | .. | .. | 35·3 | 38·5 | 33·1 |
| †1⅛ | 22¾ | 6804 | 33· | 31·75 | 29· | 29· | 27·5 | 27· | 29·5 | 26· |
| †1 | 18 | 5376 | 27·25 | 26· | 24·75 | 23· | 22·75 | 22· | 24·3 | 21·2 |
| † ⅞ | 13¾ | 4116 | 22·5 | 21·5 | 21·1 | 20·7 | 20·5 | 20·3 | 21·1 | 16·2 |
| † ¾ | 10¼ | 3024 | 15· | 14·25 | 14· | 12·75 | 12·62 | 12·5 | 13·5 | 11·9 |
| 11/16 | 8½ | 2541 | 12·3 | .. | .. | .. | .. | 10·8 | 11·4 | 10· |
| † 5/8 | 7 | 2100 | 9·87 | 9·75 | 9·5 | 9·5 | 9·5 | 9·37 | 9·5 | 8·2 |
| 9/16 | 5½ | 1701 | .. | .. | .. | .. | .. | .. | .. | .. |
| ½ | 4½ | 1344 | 6·3 | .. | .. | .. | .. | 5·9 | 6· | 5·3 |

The lines marked (†) contain the results of experiments, and the intermediate lines those derived from calculation.

TABLE III.—FOR ASCERTAINING THE STRENGTH OF HAWSER-LAID ROPE.

| Size. | No. of Yarns. | Weight, 100 Fathoms. | Strain, in Tons. | | | | Mean. |
|---|---|---|---|---|---|---|---|
| | | | Maximum. | Intermediate Strains. | | Minimum. | |
| in. | | lbs. | | | | | |
| †12 | 1173 | 2940 | 45·5 | 40·5 | 39· | 35· | 40· |
| 11½ | 1077 | .. | 41·7 | .. | .. | 32· | 36·7 |
| 11 | 987 | .. | 38·2 | .. | .. | 29·3 | 33·6 |
| 10½ | 900 | .. | 34·9 | .. | .. | 26·7 | 30·7 |
| 10 | 816 | 2136 | 31·7 | .. | .. | 24·2 | 27·9 |
| 9½ | 738 | .. | 28·6 | .. | .. | 21·8 | 25·2 |
| 9 | 660 | 1712 | 25·7 | .. | .. | 19·6 | 22·6 |
| 8½ | 591 | .. | 23· | .. | .. | 17·5 | 20·2 |
| 8 | 522 | 1379 | 20·4 | .. | .. | 15·5 | 18· |
| 7½ | 459 | .. | 18· | .. | .. | 13·6 | 15·8 |
| 7 | 399 | .. | 15·8 | .. | .. | 11·8 | 13·8 |
| 6½ | 345 | .. | 13·7 | .. | .. | 10·2 | 12· |
| †6 | 294 | 834 | 11¾ | 10¾ | 10· | 8·7 | 10·3 |
| 5½ | 249 | 712 | 9·8 | .. | .. | 7·3 | 8·7 |
| 5 | 204 | .. | 8·2 | .. | 7· | 6· | 7·2 |
| 4½ | 168 | 413 | 6·7 | .. | 5· | 5· | 5·9 |
| 4 | 132 | .. | 5·3 | .. | .. | 4· | 4·7 |
| 3½ | 102 | .. | 4·1 | .. | .. | 3·2 | 3·7 |
| 3 | 75 | 203 | 3·1 | .. | 2·5 | 2·4 | 2·8 |
| 2½ | 54 | .. | 2·2 | .. | .. | 1·8 | 2·1 |
| 2 | 33 | .. | 1·5 | .. | 1·7 | 1·3 | 1·4 |
| †1¾ | 27 | .. | 1·28 | 1·28 | 1·23 | 1·13 | 1·23 |
| †1½ | 21 | .. | ·90 | ·89 | ·88 | ·86 | ·88 |
| †1¼ | 15 | .. | ·60 | ·56 | ·55 | ·53 | ·56 |
| †1 | 12 | .. | ·58 | ·51 | ·49 | ·46 | ·51 |
| † ¾ | 9 | .. | ·51 | ·46 | ·46 | ·2 | ·46 |
| † ½ | 6 | .. | ·28 | ·28 | ·28 | ·28 | ·28 |

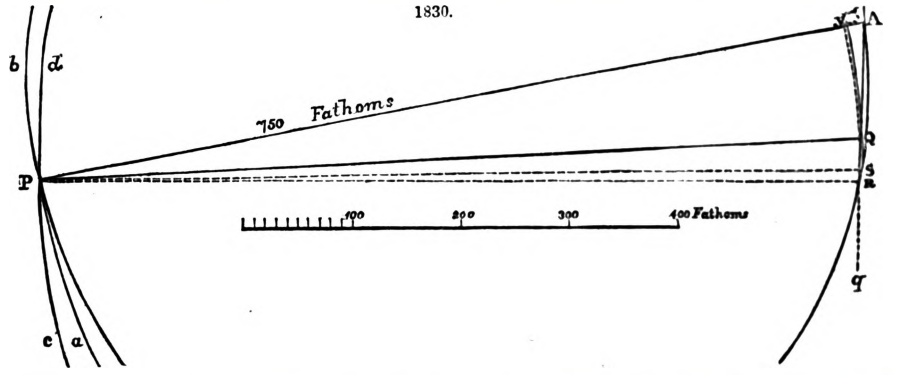
The lines marked (†) contain the results of experiments, and the intermediate lines those derived from calculation.

TABLE IV.—FOR ASCERTAINING THE STRENGTH OF ROUND-LINK CRANE CHAIN.

| Size. | Weight, 100 Fathoms. | Strain, in Tons. | | | | Mean. | Testing Strength. |
|---|---|---|---|---|---|---|---|
| | | Maximum. | Intermediate Strains. | | Minimum. | | |
| in. | lbs. | | | | | | |
| †1 5/8 | 15569 | 75· | 74·7 | 74·5 | 68· | 73· | 31·6 |
| 1 1/2 | .. | 64· | .. | .. | 58·2 | 62·3 | 27· |
| 1 7/16 | .. | 59· | .. | .. | 53·8 | 57·4 | 24·7 |
| 1 3/8 | .. | 54·2 | .. | .. | 49·6 | 52·8 | 22·6 |
| 1 5/16 | .. | 49·7 | .. | .. | 45·5 | 48·4 | 20·6 |
| 1 1/4 | .. | 45·3 | .. | .. | 41·7 | 44·1 | 18·8 |
| 1 3/16 | .. | 41·2 | .. | .. | 38· | 40·1 | 17· |
| 1 1/8 | 7481 | 37·3 | .. | .. | 34·5 | 36·3 | 15·3 |
| 1 1/16 | .. | 33·6 | .. | .. | 31·2 | 32·7 | 13·6 |
| 1 | 6490 | 30·1 | .. | .. | 28·1 | 29·3 | 12· |
| 15/16 | 5600 | 26·8 | .. | .. | 25·2 | 26·1 | 10·5 |
| 7/8 | 4500 | 23·7 | .. | .. | 22·5 | 23·1 | 9·1 |
| †13/16 | 4000 | 20·9 | 20·3 | .. | 20· | 20·4 | 7·9 |
| 3/4 | 3449 | 17·8 | .. | .. | 16·6 | 17·3 | 6·8 |
| 11/16 | 2900 | 14·9 | .. | .. | 13·5 | 14·6 | 5·6 |
| 5/8 | 2538 | 12·3 | .. | .. | 10·8 | 12· | 4·6 |
| 9/16 | 2001 | 10· | .. | .. | 8·7 | 9·7 | 3·8 |
| 1/2 | 1583 | 7·9 | .. | .. | 6·9 | 7·7 | 3· |
| 7/16 | 1060 | 6· | .. | .. | 5·2 | 5·9 | 2·3 |
| 3/8 | 827 | 4·4 | .. | .. | 3·8 | 4·3 | 1·6 |
| 5/16 | 581 | 3· | .. | .. | 2·7 | 3· | 1·1 |
| 1/4 | 392 | 1·9 | .. | .. | 1·7 | 1·9 | ·75 |
| 3/16 | .. | 1·1 | .. | .. | ·97 | 1· | ·42 |

The lines marked (†) contain the results of experiments, and the intermediate lines those derived from calculation.

*Experiments and Calculations, made by Nicholas Tinmouth, to Determine the Curvature of Chain Cables.*—Given the length of a chain cable, the vertical distance between its extremities, the tension on the upper end, and its weight 100 fathoms; to find the angle between the upper part of the cable and a vertical line, and that between the lower part of the cable and a horizontal line. Suppose the length of chain cable 100 fathoms; vertical distance between its extremities 11 fathoms; strain on the upper end 40½ tons; size of cable 1½ in., whose weight the 100 fathoms is 108 cwt. or 5·4 tons. Since 100 fathoms weigh 5·4 tons, 750 fathoms will weigh 40½ tons, or 750 fathoms attached to the upper end and hanging freely, will have the same effect as the strain of 40½ tons. Take any vertical line A Q, Fig. 1830, equal to 100 fathoms; from A as a centre, and with a radius equal to 750 fathoms describe the arc *a b*. From Q as a centre, and with a radius equal to 750 minus 11 or 739 fathoms, 11 fathoms being the vertical distance between the



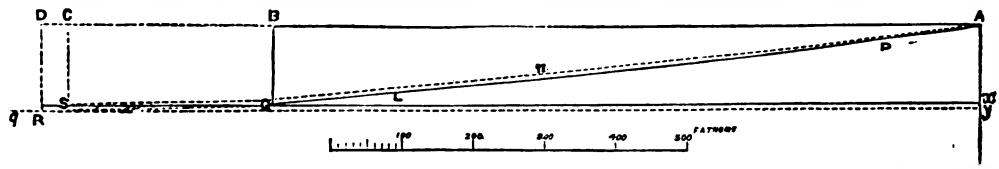

extremities, describe an arc *c d* intersecting the arc *a b* in some point P. Join P A, P Q. On P A describe a semicircle. The point Q will in this case be found to lie within the semicircle. Produce A Q to cut the semicircle in R. Join P R. From P as a centre with the radii P Q, P R, describe the arcs Q *x*, Q *y*, intersecting A P in *x* and *y*. Then P A Q is the angle which the upper part of the cable will make with a vertical line; as P A *x* = 79° 52′, Fig. 1831, and Q P R the angle which the lower part of the cable makes with a horizontal line, as L Q *x*, Fig. 1831, = 2° 28′. A *x*, Figs. 1830, 1831, is the vertical distance between the extremities of the cable. As the length A Q, Fig. 1830, of the cable is increased, the point Q approaches the point R, and the angle Q P R which the lower part makes with a horizontal line, diminishes. When the point Q coincides with R or A Q is equal to A R, the angle Q P R vanishes, and a horizontal line forms a tangent to the cable at its lowest part. Thus, in Fig. 1831, A Q R is the cable represented by A R, Fig. 1830, = 131·89 fathoms, and is a semi-catenary, the horizontal line R *y*, Fig. 1831, being a tangent to

TABLE V.—RESULTS OF CALCULATIONS ON THE CATENARY CURVE OF A CHAIN CABLE.

| Length of Cable, 100 Fathoms. | Testing Strain, 40½ Tons on the Cable. Depth. 11 Fathoms. Suspended in Air. | 11 Fathoms. Correction for the Buoyancy of Water. | 7 Fathoms. Suspended in Air. | 7 Fathoms. Correction for the Buoyancy of Water. |
|---|---|---|---|---|
| Angle between the upper end of the cable and a vertical line | 79° 52′ 16″·66 | 80° 21′ 26″·55 | 82° 9′ 50″ | 82° 38′ 28″·3 |
| Horizontal pull on the ship and anchor | .. | 39·927 tons | .. | 40·166 tons |
| Vertical force to depress the bow | .. | 6·78 tons | .. | 5·187 tons |
| Angle between lower end of cable and a horizontal line | 2° 28′ 25″·09 | 2° 57′ 59″·37 | 0° 10′ 26″·15 | 0° 39′ 19″·07 |
| Vertical force to lift the anchor | .. | 2·067 tons | .. | 0·459 ton |
| Length of semi-catenary, of which the 100 fathoms is a segment | 131·895 faths. | 143·88 faths. | 102·16 faths. | 109·71 faths. |
| The forces on the bow, and horizontal force on anchor | .. | as above | .. | as above |
| Depth of the semi-catenary, of which length 100 fathoms is a segment | 11·68 faths. | 12·136 faths. | 7·0034 faths. | 7·055 faths. |
| Lower part hangs horizontally, hence force to lift anchor | .. | 0 | .. | 0 |
| Length of semi-catenary at the depth specified in the respective columns, or the greatest length of cable that can be employed, so that no part of it shall lie on the ground | 127·98 faths. | 137·03 faths. | 102·23 faths. | 109·29 faths. |
| Angle between the upper end of this semi-catenary and a vertical line | 80° 10′ 29″·88 | 80° 49′ 15″·3 | 82° 9′ 56″·94 | 82° 40′ 12″·38 |
| Horizontal pull on ship and anchor | .. | 39·98 tons | .. | 40·1688 tons |
| Vertical force to depress the bow | .. | 6·46 tons | .. | 5·167 tons |
| Lower part hangs horizontally, hence force to lift the anchor | .. | 0 | .. | 0 |

it at its lowest point R; the vertical distance between its extremities being D R or A $y$ = 11·68 fathoms, which corresponds with A $y$, Fig. 1830, measured on its proper scale. A Q, Figs. 1830, 1831, is a segment of the semi-catenary A R. Hence a diagram being constructed as above, if the point Q, Fig. 1830, should be found to lie *within* the semicircle, the cable forms a segment of a semi-catenary, and its lower part makes an angle with a horizontal line; if the point A O, Fig. 1831, lie in the *circumference* of the semicircle, the cable forms a complete semi-catenary, to the lowest point of which a horizontal line forms a tangent. If the point Q be found to lie *without* the semicircle as $q$, Fig. 1830, the length A R will form a semi-catenary; and the remaining portion R $q$, which is beyond the semicircle will rest on the ground, as R $q$, Fig. 1831.

1831.




If it be required to ascertain what length of chain cable will form a complete semi-catenary, at the proposed depth A $x$, or 11 fathoms; let the arc $x$ Q, Fig. 1830, be continued until it intersects the semicircle in some point S; join A S, P S, then A S is the length required; which is the greatest length of cable that can be employed with a depth of 11 fathoms, so that no part of it shall rest on the ground, as A $n$ S, Fig. 1831. The angle P A Q, Fig. 1830, or P A $x$, Fig. 1831, which the upper part of the cable makes with a vertical line, may be found from the following expression: cos. $\mathrm{P\,A\,Q} = \dfrac{(\mathrm{P\,A})^2 + (\mathrm{A\,Q})^2 - (\mathrm{P\,Q})^2}{2 \times \mathrm{P\,A} \times \mathrm{A\,Q}}$. Substituting for P A, 750 fathoms; for P Q, 739 fathoms; and for A Q, 100 fathoms:

$$\text{cos. P A Q} = \frac{(750)^2 + (100)^2 - (739)^2}{2 + 750 \times 100} = 0{\cdot}17586 \text{ to rad. 1.}$$

And from a table of cosines we have angle P A Q, or P A $x$, Fig. 1831, = 79° 52′ 16″·66.

The angle Q P R, Fig. 1830, or L Q $x$, Fig. 1831, which the lower part of the cable makes with a horizontal line, may be found from the following expression:

$$\text{sin. Q P R} = \frac{(\mathrm{P\,A})^2 - (\mathrm{P\,Q})^2 - (\mathrm{A\,Q})^2}{2 \times \mathrm{A\,Q} \times \mathrm{P\,Q}}.$$

100 FATHOMS IN LENGTH AND 1½-IN. IN DIAMETER, UNDER GIVEN STRAINS AND DEPTHS OF WATER.

| Minimum Breaking Strain, 54½ Tons on the Cable. | | | | Mean Breaking Strain, 59½ Tons on the Cable. | | | |
|---|---|---|---|---|---|---|---|
| Depth. | | | | Depth. | | | |
| 11 Fathoms. | | 7 Fathoms. | | 11 Fathoms. | | 7 Fathoms. | |
| Suspended in Air. | Correction for the Buoyancy of Water. | Suspended in Air. | Correction for the Buoyancy of Water. | Suspended in Air. | Correction for the Buoyancy of Water. | Suspended in Air. | Correction for the Buoyancy of Water. |
| 80° 51′ 16″·28 | 81° 12′ 45″·12 | 83° 8′ 54″·17 | 83° 29′ 9″·55 | 81° 5′ 35″·25 | 81° 25′ 13″·31 | 83° 23′ 14″·61 | 83° 42′ 25″·46 |
| .. | 53·86 tons | .. | 54·148 tons | .. | 58·834 tons | .. | 59·14 tons |
| .. | 8·326 tons | .. | 6·17 tons | .. | 8·876 tons | .. | 6·52 tons |
| 3° 28′ 10″·54 | 3° 49′ 52″·29 | 1° 9′ 59″·26 | 1° 31′ 54″·18 | 3° 42′ 38″·55 | 4° 2′ 27″·78 | 1° 24′ 25″·45 | 1° 43′ 43″·19 |
| .. | 3·6 tons | .. | 1·448 ton | .. | 4·156 tons | .. | 1·784 ton |
| 160·41 faths. | 176·43 faths. | 120·403 faths. | 130·32 faths. | 170·598 faths. | 188·06 faths. | 126·88 faths. | 137·67 faths. |
| .. | as above | .. | as above | .. | as above | .. | as above |
| 12·83 faths. | 13·55 faths. | 7·207 faths. | 7·43 faths. | 13·286 faths. | 14·106 faths. | 7·33 faths. | 7·568 faths. |
| .. | 0 | .. | 0 | .. | 0 | .. | 0 |
| 148·6 faths. | 159·018 faths. | 118·56 faths. | 126·74 faths. | 155·35 faths. | 166·16 faths. | 124·00 faths. | 132·42 faths. |
| 81° 32′ 0″ | 82° 5′ 9″·08 | 83° 14′ 52″·96 | 83° 40′ 41″·5 | 81° 53′ 41″·5 | 82° 25′ 32″·74 | 83° 32′ 18″·14 | 83° 56′ 2″·35 |
| .. | 53·981 tons | .. | 54·168 tons | .. | 58·98 tons | .. | 59·166 tons |
| .. | 7·5 tons | .. | 6·00 tons | .. | 7·842 tons | .. | 6·27 tons |
| .. | 0 | .. | 0 | .. | 0 | .. | 0 |

Substituting, as before, the proper values of P A, P Q, and A Q,

$$\text{sin. Q P R} = \frac{(750)^2 - (739)^2 - (100)^2}{2 \times 100 \times 739} = 0{\cdot}043159 \text{ to rad. 1.}$$

And from a table of sines we have angle $\underset{\text{or L Q } x}{\text{Q P R}} = 2° 28′ 25″{\cdot}09$

The greatest length of cable that can be employed with a depth of 11 fathoms so that no part of it may rest on the ground is A S, which is equal to $\sqrt{(\text{A P})^2 - (\text{P S})^2}$. Substituting for A P and P S their values $\left.\begin{matrix}\text{A S, Fig. 1830} \\ \text{or A } n \text{ S, Fig. 1831}\end{matrix}\right\} = \sqrt{(750)^2 - (739)^2} = 127{\cdot}9$ fathoms.

The angle P A S, which this length of cable makes with a vertical line may be found from the expression $\text{sin. P A S} = \frac{\text{P S}}{\text{P A}}$. Now P S = P Q = 739 fathoms, and P A = 750 fathoms. Hence, by substitution, $\text{sin. P A S} = \frac{739}{750} = 0{\cdot}9853$ to radius 1; and from a table of sines we have

$$\left.\begin{matrix}\text{angle P A S, Fig. 1830} \\ \text{or angle P A } x\text{, Fig. 1831}\end{matrix}\right\} = 80° 10″ 29{\cdot}88.$$

The position which a chain cable would assume under any given circumstances may also be obtained experimentally, by the suspension of a small chain of any convenient length.

Let it be required to find by experiment on a chain $\frac{9}{16}$ of an in. in diameter and 25 ft. long, the position which a 1½-in. chain cable would take, whose length is 100 fathoms, vertical distance between the extremities 11 fathoms, and strain on the upper end 40½ tons:

The weight of 100 fathoms of 1½-in. chain cable is 108 cwt.
" " " $\frac{9}{16}$-in. " 15 cwt. 0 qr. 21 lbs.

The proportionate strain to be applied to the $\frac{9}{16}$-in. chain may be found from the following expression:

$$= \frac{\text{Weight of chain the 100 fathoms}}{\text{Weight of cable the 100 fathoms}} \times \frac{\text{length of chain}}{\text{length of cable}} \times \text{strain}$$

$$\text{cwt. qr. lbs.} \qquad \text{ft.} \qquad \text{tons. cwt. qrs. lbs.}$$

$$= \text{(by substitution)} \frac{15\ 0\ 21}{108} \times \frac{25}{600} \times 40\tfrac{1}{2} = 4\ \ 2\ \ 27{\cdot}552.$$

The length of the experimental chain being $\frac{1}{24}$ the length of the cable, the vertical distance between the extremities of the chain should be taken $\frac{1}{24}$ of 11 fathoms, or 2 ft. 9 in.

The curve formed by the cable suspended under these circumstances was similar to that derived

from calculation for a 1½-in. chain cable of 100 fathoms on a $\frac{1}{24}$ scale. The deflection at the middle of the length from a straight line joining the extremities of the chain measured 5 in. This deflection, multiplied by 24, gives the deflection on the full scale 10 ft., agreeing with the result of calculation.

Let one end of a chain cable be made fast, and a given strain act on the other end; both extremities being in the same horizontal line, to find by construction the depth of the lowest part of the chain; let the size of the cable be 1½ in., length 100 fathoms, strain 40½ tons. Take a vertical line A R, Fig. 1830, equal to one-half the length of the cable, or 50 fathoms; from R draw the line R P at right angles to A R; from A as a centre, with a radius equal to 750 fathoms, or the number of fathoms of a 1½-in. chain cable due to 40½ tons strain, describe an arc *a b* cutting R P in P; join P A; from P as a centre, with a radius P R describe the arc R *y* cutting A P in *y*. A *y* is the required depth of the lowest part of the chain.

The same may also be found from the expression

$$\text{Depth of lowest point of cable} = T - \sqrt{T^2 - s^2};$$

where T is equal to P A, the tension at A in fathoms of chain, or 750 fathoms· and *s* is equal to A R the half-length of cable, or 50 fathoms. Hence, by substitution,

$$\text{Depth of lowest point of cable} = 750 - \sqrt{(750)^2 - (50)^2},$$
$$= 750 - 748{\cdot}331 = 1{\cdot}668 \text{ fath.}$$
$$6$$
$$10{\cdot}008 \text{ ft.}$$

The deflection of a cable from a horizontal line may also be found experimentally, by the suspension of a small chain of any assumed length.

Let the size of the experimental chain be $\frac{9}{16}$, length 25 ft., weight the 100 fathoms, 15 cwt. 0 qr. 21 lbs.

The proportionate weight to be attached

$$= \frac{\text{Weight of chain the 100 fathoms}}{\text{Weight of cable the 100 fathoms}} \times \frac{\text{length of chain}}{\text{length of cable}} \times \text{strain}$$

$$= \text{(by substitution)} \frac{\overset{\text{cwt. qr. lbs.}}{15\ 0\ 21}}{108} \times \frac{\overset{\text{ft.}}{25}}{600} \times 40\tfrac{1}{2} = \overset{\text{tons. cwt. qrs. lbs.}}{4\ \ 2\ \ 27{\cdot}552}.$$

The length of the chain in this experiment being $\frac{1}{24}$ the length of the chain cable, the curve observed is the curve on a $\frac{1}{24}$ scale, which the cable will form.

The deflection was found to be $4\frac{15}{16}$, which being multiplied by 24 gives the deflection, or depth of the lowest point of the cable of 100 fathoms with 40½ tons strain, equal to 9 ft. 10½ in. Let the same be tried with 12½ ft. of ⅜-in. chain, weighing 7·96 cwt. to the 100 fathoms.

Proportionate weight to be attached

$$= \frac{\text{Weight of chain the 100 fathoms}}{\text{Weight of cable the 100 fathoms}} \times \frac{\text{length of chain}}{\text{length of cable}} \times \text{strain}$$

$$= \text{(by substitution)} \frac{7{\cdot}96}{108} \times \frac{\overset{\text{ft.}}{12\frac{1}{2}}}{600} \times 40\tfrac{1}{2} = \overset{\text{tons. cwt. qr. lbs. oz.}}{1\ \ 0\ \ 27\ \ 4{\cdot}7}.$$

The length of chain in this experiment being $\frac{1}{48}$ of the length of cable, the curve observed is that on a $\frac{1}{48}$ scale, which the cable will form. The deflection was found to be $2\frac{5}{16}$ of an in., which multiplied by 48 is 9 ft. 3 in., the depth of the lowest point of the cable.

Let the size of the cable be as before 1½ in., and the strain 40½ tons, but the length 12½ fathoms. Take a vertical line A R, Fig. 1831, equal to one-half the length of the cable, or 6¼ fathoms; from R draw the line R P at right angles to A R; from A with the radius 750 fathoms, being the number of fathoms of a 1½-in. chain cable due to a strain of 40½ tons, describe an arc *a b* cutting R P in P; join P A; from P with the radius P R describe the arc R *y* cutting A P in *y*. A *y* is the required depth of the lowest point of the chain.

The same may also be found from the expression

$$\text{Depth of lowest point of cable} = T - \sqrt{T^2 - s^2};$$

where T is equal to P A, the tension of A in fathoms of chain, or 750 fathoms; and *s* = A R, the half-length of the cable, or 6·25 fathoms. Hence, by substitutior

$$\text{Depth of lowest point of cable} = 750 - \sqrt{(750)^2 - (6{\cdot}25)^2}$$
$$= 750 - 749{\cdot}974 = 0{\cdot}026 \text{ fath}$$
$$6$$
$$0{\cdot}156 \text{ ft.}$$
$$12$$
$$1{\cdot}872 \text{ in.}$$
$$= 1\tfrac{7}{8} \text{ in. nearly.}$$

The deflection may also be found by experiment. Suppose a length of 25 ft. of $\frac{9}{16}$ chain, weighing 15 cwt. 0 qr. 21 lbs. to the 100 fathoms, be taken for the experiment.

Then the proportionate weight to be attached is

$$= \frac{\text{Weight of chain the 100 fathoms}}{\text{Weight of cable the 100 fathoms}} \times \frac{\text{length of chain}}{\text{length of cable}} \times \text{strain}$$

$$= \text{(by substitution)} \frac{\overset{\text{cwt. qr. lbs.}}{15\ 0\ 21}}{108} \times \frac{\overset{\text{ft.}}{27}}{\underset{\text{tons.}}{75}} \times 40\tfrac{1}{2} = \overset{\text{ton. cwt. qrs. lbs.}}{1\ \ 17\ \ 3\ \ 24\tfrac{1}{2}}.$$

The length of the chain in this experiment being $\frac{1}{3}$ the length of the chain cable, the curve observed is that which the cable will form on a scale of $\frac{1}{3}$.

The deflection was found to be $\frac{13}{16}$ of an in., which, multiplied by 3, is equal to $2\frac{7}{16}$ in. On the addition of $\frac{1}{2}$ cwt. to the above weight, the deflection was $\frac{5}{8}$ of an in., which, multiplied by $3 = 1\frac{7}{8}$, agreeing with the calculation. As the nip on the roller where the weight was attached was considerable, it is probable that the chain was not sufficiently free.

The experiment was also tried with a $\frac{3}{8}$-in. chain, weighing 7·96 cwt. the 100 fathoms, and $12\frac{1}{2}$ ft. long.

The proportionate weight to be attached

$$= \frac{\text{Weight of chain the 100 fathoms}}{\text{Weight of cable the 100 fathoms}} \times \frac{\text{length of chain}}{\text{length of cable}} \times \text{strain}$$

$$= \text{(by substitution)} \frac{7{\cdot}96}{108} \times \frac{\overset{\text{ft.}}{12\frac{1}{2}}}{\underset{\text{tons.}}{75}} \times 40\tfrac{1}{2} = 0{\cdot}49766 = \overset{\text{ton. cwt. qrs. lbs.}}{9\ \ 3\ \ 22{\cdot}32}$$

The length of the chain in this experiment being $\frac{1}{6}$ of the length of the cable, the curve observed is that, on a scale of $\frac{1}{6}$, which the cable will form.

The deflection was found to be $\frac{5}{16}$, which, multiplied by 6, is equal to $\frac{30}{16} = 1\frac{7}{8}$ in., which agrees with the calculation.

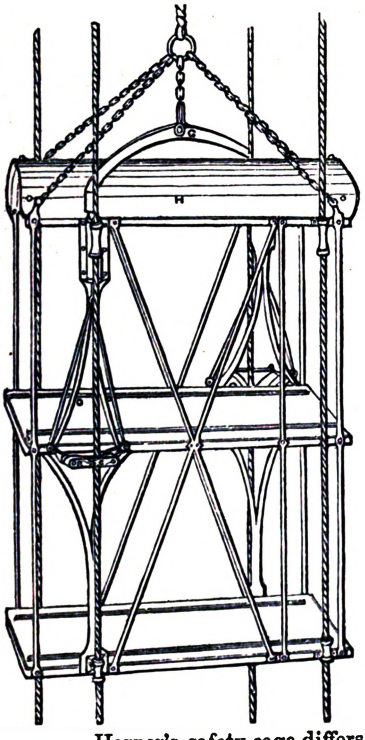
The weight attached was $1\frac{1}{2}$ lb. more than should have been employed.

Where the result of the experiment does not exactly agree with that of calculation, it is owing an imperfection in the experiment. See ANCHOR. FOUNDING, CASTING, AND FORGING. MATERIALS OF CONSTRUCTION, *Strength of*. ROPE-MAKING MACHINERY.

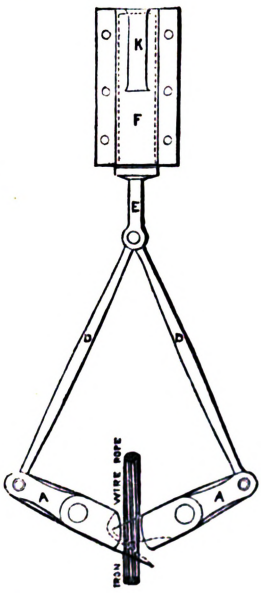
CAGE, SAFETY. FR., *Cuffat des mines de houille;* GER., *Kübel, Fahrstuhl;* ITAL., *Gabbia di sicurezza.*

The safety-cage of J. P. Harper with conducting ropes of iron wire is represented and the mechanical arrangements illustrated in Figs. 1832 to 1835. Fig. 1832 is of this cage in working order; Fig. 1833, sectional elevation of compressors when not in action: Fig. 1834, sectional elevation of the compressors when first brought into action; and Fig. 1835, elevation of compressors when in extreme action, showing the conducting iron-wire rope in a compressed state.

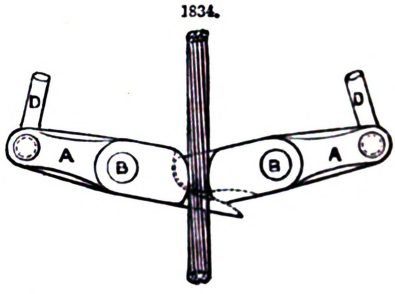
1832.



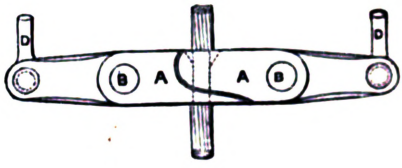

1833.




1834.




1835.




Harper's safety-cage differs both in principle and detail from any that have preceded it, and certainly stands alone in this respect, that it is specially designed, constructed, and adapted for the ordinary wire-rope conductors.

Safety-cages have hitherto been brought out more particularly for adaptation to the wooden guides, but, as these are becoming superseded by the iron-wire ones on account of their durability and cheapness—if safety-cages are to be universally adopted, they must be made applicable to wire-rope conductors.

Safety-cages can be used to greater advantage in connection with the iron-wire than with the wooden guides, for, with the wooden ones, sharp-pointed or toothed instruments are usually brought to clutch or dig into the conductor; and if it so happens that the length of guide-rods on which the apparatus is brought to play be rotten, unsound, infirmly fixed, or in any way defective, the safety apparatus is of no avail; indeed sometimes, be the rods ever so sound and in good repair, we hear of accidents occurring, owing to the guide-rods being split and ripped down by the apparatus brought to bear on them.

Accidents of this description are less liable to occur with the iron-wire guides. It has been found that it would not do to employ an instrument with a sharp point, a toothed or uneven surface, to bear on the conductors, for, as the circumference of a wire rope is uneven, they would cut and injure the more prominent parts.

This safety-cage acts effectually without damaging or depreciating in the least the wire conductors, of whatever description they may be. The apparatus is extremely simple, substantial, inexpensive in its construction, is not easily deranged, and can be applied to cages and hoists, of whatever description or size, whether conducted at the ends, corners, or sides, and carrying any weight. The principle by which the apparatus, on the severance of the winding-rope from the cage, is brought to bear on the conductors is by compression; and its operation is (of its own accord) to bring the cage to an immediate stand by means of catches or compressors, which fasten on, encircle, and compress *not only the sides* but the *whole circumference* of the conductor. When the winding-rope is readjusted by the tension of the rope, the compressors at the same instant release their grasp of the conductors, and the whole is again in working order.

The general features of the cage will be readily seen on examining Fig. 1832. The catches, or more properly the compressors, are of peculiar shape: Figs. 1833 to 1835 show their positions when out of play and held from the guides by the tension of the rope, the position they assume when first brought into play, and the iron-wire guide in extreme compression. This will, of course, vary in proportion to the weight on the cage at the time they are brought into requisition.

Fig. 1832 is a design for double cages in a 13-ft. shaft, fitted with wire-rope conductors, each cage having two, three, or four guides as may be required, and single or double tiered to carry either two or four wagons.

The cage, Fig. 1832, though conducted by four guides, the apparatus is brought to bear on two only, that is, across the corners. The compressors, A, Fig. 1835, made of malleable iron and case-hardened, are of peculiar construction, made in a fork-like shape, and of any proportionate elevational depth: see Fig. 1834. They work on each side of the conductors on axles B attached to the cage, and when not in play are held by the tension of the winding-rope at an acute angle; and, when brought into play, slide into each other, and encircle the conductor, assuming a nearly horizontal position, and forming, both in plan and elevation, a circular hole the full depth of the compressors, but less in diameter than the conductor, so that as the angle is made to increase in proportion to the weight on the cage, so will the compression also increase on the conductors.

The compressors A are constructed with lever ends, and when the cage hangs freely on the winding-rope they are held away from the conductors by side rods D, attached on each side of the cage to main vertical and shouldered rods E working through guide-boxes F, in which are inserted spiral springs (merely to give impetus to the compressors) bearing on the inside shoulders of the main vertical rods E, which are connected on each side of the cage by a cross-bar G, working over the top or cover of the cage H, and attached to the winding-rope. To prevent the compressors A wrenching apart, they are connected by a front tie-plate C. K represents ordinary cast-iron guide-boxes through which the conductors slide.

It will be seen that when the cage hangs freely on the rope the shoulders on the main vertical rods E are brought up by means of the cross-bar G to the under-sides of the guide-boxes F, and the compressors, now being held away from the conductors, are allowed to pass freely between the forks of the catches; but immediately on the rope becoming disconnected from the cross-bar G the concealed spiral springs, hitherto held in subjection, are released, give impetus to and assist in bringing the compressors A into instantaneous play, which, then sliding into one another, so close round and compress the conductor into a circular hole, less in diameter than the conductor itself, through which it is impossible for it to pass; hence the cage is brought to an immediate stand.

In the arrangements by which the compressors are connected to the winding-rope, it will be perceived that both sets must work simultaneously on the guides, and are such as cannot be easily deranged.

CAISSON. Fr., *Caisson;* Ger., *Versenkkasten;* Ital., *Cassone a cilindro;* Span., *Cajon.*

Floating bodies, constructed of sheet iron, designed to open or close the entrances of a docks or basins, are termed caissons.

The engravings, Figs. 1836, 1837, represent one of the caissons for closing dock or basin entrances at Haulbowline Navy Yard, Cork, constructed by A. Clarke. It is one of the class termed sliding caissons, and is drawn into a recess formed for its reception at right angles to the entrance of the dock or basin, when the entrance is opened to allow ships to pass in or out. Such caissons are also used as roadways for the traffic, usually very heavy, passing across the entrance of the dock or basin.

The object sought is to preserve the roadway or deck of the caisson level with the wharf on one side of the entrance and with the cover of the recess on the other side when the caisson is in its place and being used as a roadway; likewise to keep the sides of the entrance level and free from obstruction when the caisson is drawn into its recess, and the operation of taking ships into

or out of the dock or basin is in progress. These objects have hitherto been accomplished by making the deck of the caisson capable of being lowered, when it is necessary to draw the caisson into and under the cover of the recess, or by lowering the caisson bodily by sinking it to a sufficient depth to admit of its passing below the cover.

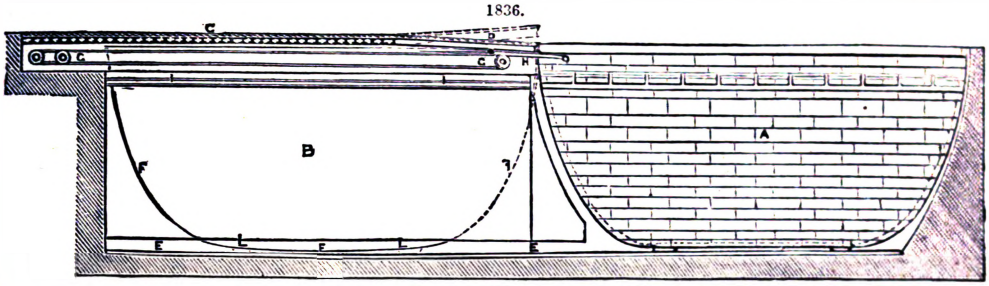
In the present instance a third method has been adopted, that of raising and lowering a part of the cover of the recess sufficiently to allow the caisson to pass down a series of slopes at the bottom of the recess and entrance; these slopes being so adjusted that when the caisson is drawn completely into its recess it has become lowered to a very small extent, and at the same time so thrown out of the level as to fit under the cover, which for this purpose is formed with a slight inclination towards the entrance. The part of the cover which was raised to allow the caisson to pass is then lowered, and the wharf is clear for docking operations.

The flotation of the caisson is so adjusted that the portion of its weight borne by the masonry of the entrance is small, being only sufficient to keep the caisson steady when moving. The power, therefore, required to force it up the slopes on which it slides is but trifling, and means are provided by which it can be made to float completely if necessary.

The machinery for lifting the cover of the recess, and that for moving the caisson, will be worked by a small steam-engine. A pair of endless chains on either side of the upper part of the recess supply the moving power for the caisson.

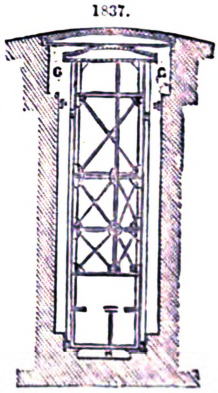
Referring to the drawing, A is the caisson in its place across the entrance, B is the recess into which it is drawn, C is the cover of the recess, and D the portion of the cover which is raised, as

1836.




shown by the dotted line, to allow the caisson to pass into the recess; E E E are the slopes on which the caisson slides, and the dotted line F shows the position of the caisson when drawn into the recess, after which the cover D is lowered into its former position. G G are the endless chains which are attached to the swivelling cross-head H connected to the caisson. I, I, I, are rubbing-pieces; K is a trap for mud; and L the skids on which the caisson slides, which are so formed as to clear the sliding ways E of any mud which may have accumulated.

1837.




The caisson can be used as an ordinary floating caisson when disconnected from the cross-head H; and by temporarily placing one of these caissons on either side of the basin entrance, and pumping the water out from between them, access to the caisson recess can be obtained for cleaning and repairs.

Many chest-like vessels, in both civil and military engineering, are termed *caissons*. In military engineering a chest that contains ammunition, and also the wagon or tumbril which conveys military stores, is called a caisson. A chest filled with explosive materials to be laid in the way of an enemy, as under some work at the possession of which he is aiming, and to be fired when the enemy is exposed to its effect; a wooden box or frame of strong timbers, used for laying the foundations of a *bridge* in situations where the coffer-dam cannot be employed; and other structures, receive the appellation caisson.

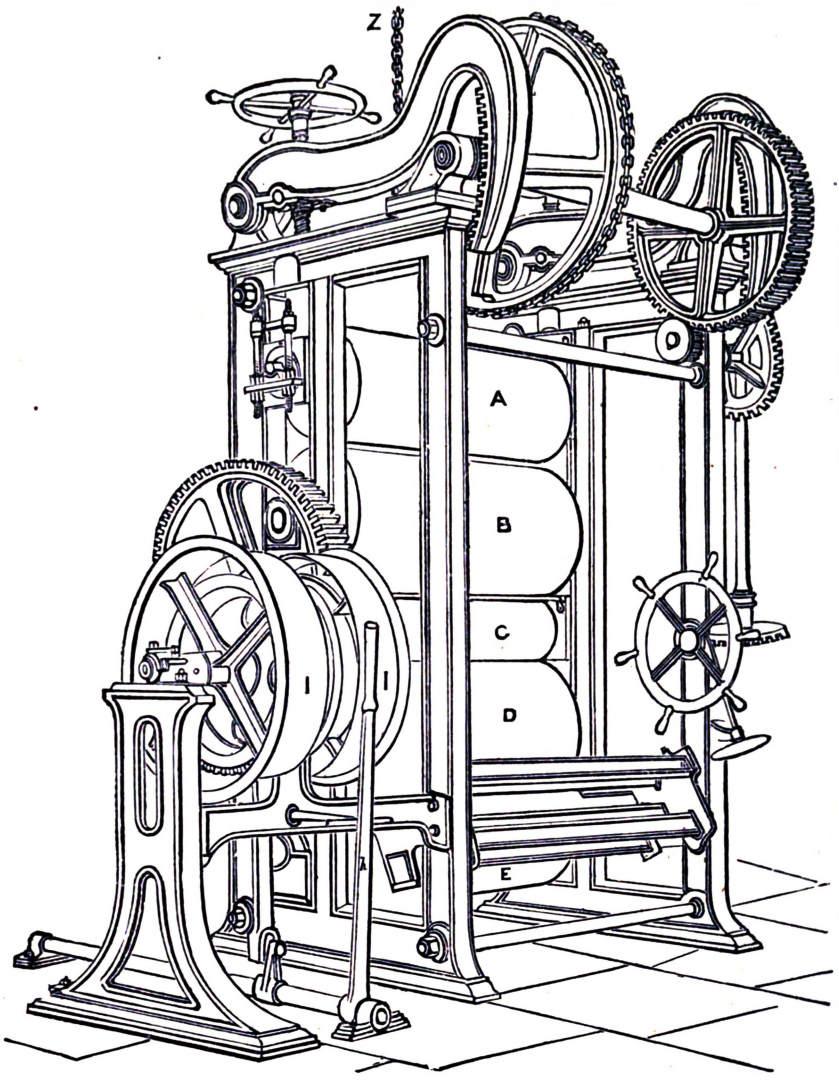
See Bridge. Docks. Fortification. Locks. Ordnance.

**CALENDER.** Fr., *Calandre;* Ger., *Calender;* Ital., *Sopressa;* Span., *Calandria.*

*Calender, Five-roller, by Thomson Brothers and Co., of Dundee.*—The arrangement of this calender is illustrated in Fig. 1838. It may be modified to finish either linen or cotton goods. This machine may be employed to effect:—*Plain calendering*, by passing the cloth through the rollers; *Chesting*, or rolling cloth on the top roller under heavy pressure, either without or after passing it through the other rollers; and *Mangling*, or rolling the cloth on the second roller from the top; to effect this object, the end of the piece being sewed to the body of the cloth, the calender is kept revolving under heavy pressure backwards and forwards. A drag or slip is made between the centre driving-roller and the lower cast-iron roller when the machine is employed for *Glazing;* the centre driving-roller may be heated either by steam or by hot bolts, the latter being necessary for high glaze. The top and bottom rollers A E, Fig. 1838, are of cast iron, 20 in. in diameter, with wrought-iron journals to sustain the pressure to which they may be subjected. The centre roller C, 11 in. diameter, is made hollow, and fitted at the ends with stuffing-boxes for the admission of steam. The two paper rollers, B D, 24 in. diameter with 54 in. width of paper, have wrought-iron journals and end-plates. The two upper rollers have small pivots set into the ends of the journals for the purpose of suspending them by rods from top-blocks while the cloth is being drawn off by the *stripping* motion, after the operation of chesting or mangling. The machine, Fig. 1838, is driven by a shaft connected by a wheel and pinion to the centre roller. This shaft carries two pulleys I I, for open and for cross belts, each pulley being 34 in. diameter, and the belts 8 in. broad;

a double friction clutch is placed between the pulleys, for the purposes of starting, reversing, or stopping the machine—the handle *h* being retained in a central position by a spring catch. The calender does not require to be attached to side walls; a foundation capable to carry its weight is sufficient. The crane motion for lifting the levers and top rollers is fixed to the frame, and the top rollers are held in position, when suspended, by a friction strap which also serves to lower the rollers. The blocks for the journals of the rollers are not attached to the framing, the brasses

1838.



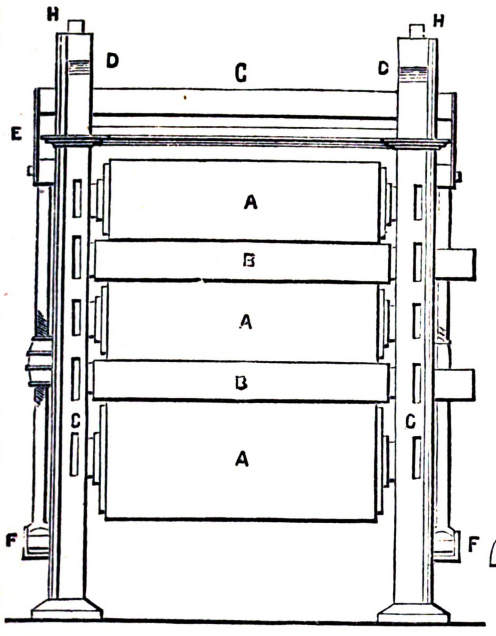

being set forward by side screws when they wear in the blocks, thus keeping the rollers in the centre; the upper part of the block being made hollow, so that the journal may be lubricated. Pressure is applied by weights suspended by the chain at Z, which is coiled on the screw pulley, and is equal to about 22 tons, which includes the weight of the rollers. By reversing the chain on the screw pulley, the weights, when a light pressure is required, may be made to counterbalance the weight of the levers and top rollers.

*Calender with Five Rollers; designed and constructed by A. More.*—Fig. 1839 is an end view; Fig. 1840, a side elevation. The same letters of reference denote the same parts in each view. A, A, A, three cylinders or rollers made of paper, the construction of which will be noticed afterwards. B B, two cast-iron cylinders, made hollow to allow of the introduction of hot bolts within them: or of steam when it is required. C C, the two side frames into which are fitted the several brass bushes for the cylinders to turn upon. D D, top guides into which the cross-head G and elevating screws H H work. E E, top-pressure levers connected by a strong rod of iron with the under-pressure lever F. This system of levers is connected with the cross-head G by two strong links of iron. The elevating screws H H pass through the cross-head, and rest upon a strong cast-iron block, into which is fitted the brass bush of the top paper roller. By means of the screws, the cross-head and levers can be raised or depressed as required, and when the calender is working warm and requires to be stopped, the elevating screws are screwed up for the purpose of lifting the paper rollers off the hot cylinders, to prevent their being injured by the heat.

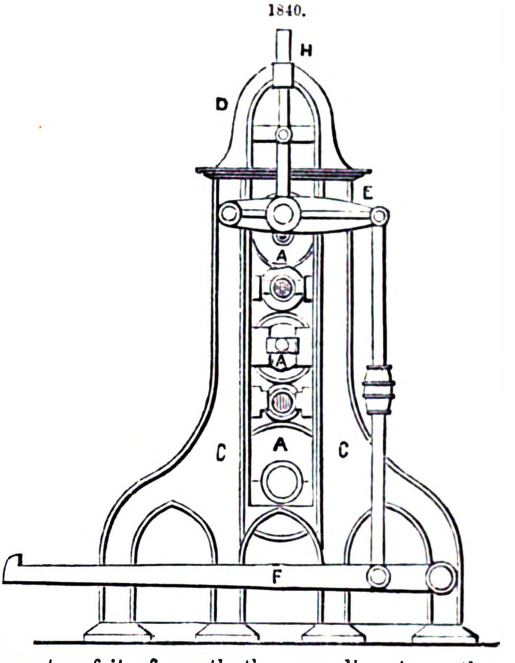
The construction of the paper rollers or cylinders is as follows:—Upon each end of a journal

of malleable iron, of sufficient strength to withstand the necessary pressure without yielding, is fastened a strong plate of cast iron, of the same diameter as the roller to be made; the plate is secured in its proper place by a ring of iron, cut in two, and let into a groove or check turned in the journal. When the roller is finished, the annular pieces are kept in their groove by a hot hoop put upon the outside of them and allowed to cool. A plate is fitted on the other end, of exactly the same size, and in the same manner. In building the rollers, one of the plates is taken off the journal, but the other is allowed to remain in its place. The paper sheets of which the rollers are

1839.

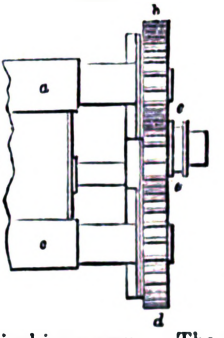



1840.

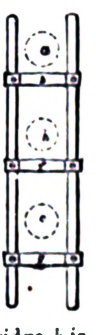



to be made have each a circular hole cut in the centre of it, of exactly the same diameter as the journal. The sheets are then put upon the journal, and pressed hard against the fixed plate. When the journal is filled with paper, it is put into a strong hydraulic press and pressed together, always adding more paper to make up the deficiency caused by compression, until the mass will press no harder. The half rings are then put in their place, to prevent the plate from being pressed back by the elasticity of the paper. The roller is now to be dried sufficiently in a stove, the heat of which causes the paper to contract so as to be quite loose. The roller is then again taken to the press, and the unfixed plate being removed, more paper is added, and the whole again compressed until the roller is hard enough for the purpose to which it is to be applied. It is next turned truly in a lathe till it acquires a very smooth surface. The woodcut, Fig. 1841, shows the manner in which the calender is geared to make it a glazing calender. In this cut, *a* marks the top cylinder of the calender, upon which is keyed a spur-wheel *b*; and *c* is the under cylinder, upon which is also keyed a spur-wheel *d*. The intermediate or carrier wheel *e e*, when drawn into gear, reduces the speed of the under cylinder *c* one-fourth. Now, the cylinder *a* being the one that gives motion to all the rollers, and revolving always at the same speed, the cloth, in its passage through all the rollers below the cylinder *a*, is carried through at a speed one-fourth less than if it passed only below the cylinder *a*; consequently, when it comes into contact with *a*, it is rubbed and thereby *glazed*, in consequence of the cylinder *a* moving one-fourth quicker than the cloth, as above stated. The woodcut, Fig. 1842, shows the manner in which the rollers are lifted clear of each other when the machine is stopped. In this, *e e* are two rods of iron attached to the block or seat of the top roller; *b f g*, three bridges of malleable iron, capable of sliding upon the rods *e e*, but held fast upon the rods when once they are adjusted to their proper places by pinching-screws. The bridge *b* is placed ½ an in. clear of the bearing of the cylinder *a*, when all the rollers are resting upon each other; the bridge *f* is placed 1 in. below the bearing of the paper roller *h*; and the bridge *g* is placed 1½ in. below the bearing of the cylinder *c*. When the pressure-screws of the calender are lifted, the blocks of the top roller being attached to them, the rods *e e* are lifted also, and along with them the different rollers, as the bridges successively come into contact with their respective bearings.

1841.



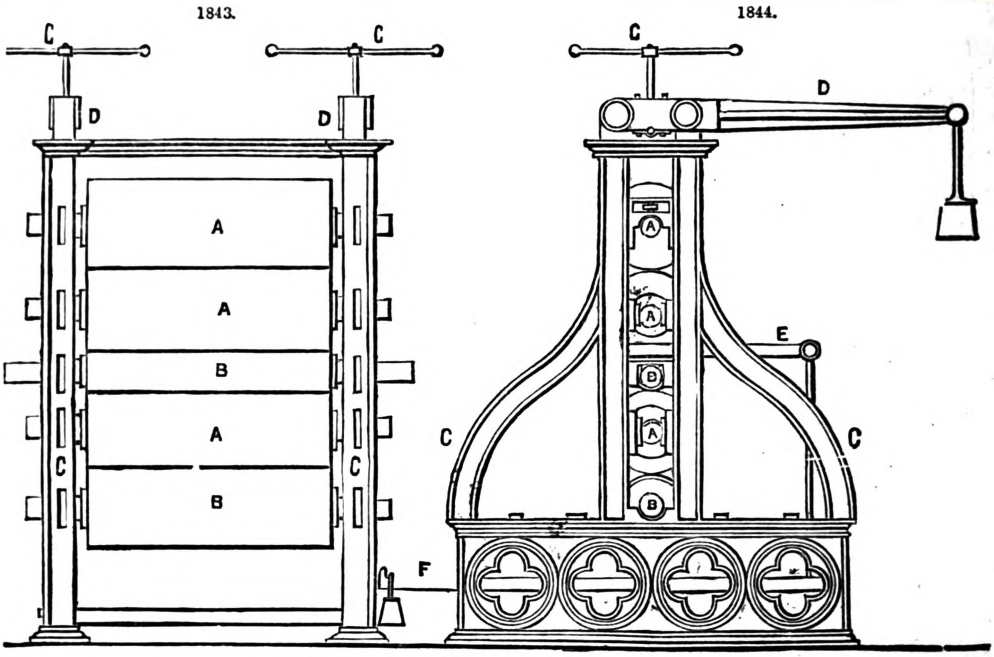

1842.



The manner of passing the cloth through the calender varies very much according to the amount of finish required upon it. The various methods are accomplished by different arrangements of the gearing, so that a calender calculated to do all the different kinds of finishing becomes a very complicated machine, on account of the quantity of gearing required. For common finishing

the method of passing the cloth through the calender is as follows:—The cloth is passed alternately over and under a series of rails placed in front of the machine, so as to remove any creases that may be in it, and is then introduced between the lower roller A and cylinder B; returns between the lower cylinder B and the centre roller A; passes again between the central A and the upper B, and again returns between the top pair A B, where it is wound off on a small roller (hid in the drawings by the framing of the machine), pressing against the surface of the top roller A. When this small roller is filled with cloth it is removed, and its place supplied by another, to be in succession filled as the motion of the machine progresses.

*Water-Mangle, with Two Copper and Three Wooden Rollers; designed and constructed by A. More.*—This machine, Figs. 1843, 1844, differs nothing in principle and little in general construction




from the five-rollered calender above described, except in this, that it is intended for wet goods, it is drawn on a scale slightly less, but the views given and the lettering of the parts correspond to those of the preceding figures. A, A, A, three wooden rollers, and B B the two copper rollers of the mangle. These last consist of a copper cover upon a cast-iron body, through which passes a wrought-iron journal, differing from those of the wooden rollers in being round, whereas these are square between the bearings. The smaller of the two copper rollers, namely, the third in order, is in this arrangement the driver, the mangle being driven like the calender, by a system of reversing gear not shown in the drawings.

The pressure in the mangle is brought on by a system of levers, which differs slightly from that described. In this indeed there are strictly two distinct pressures: that brought on the axis of the middle roller by the lever E, which is connected by a link with the weighted lever F; and that transmitted through the whole system of rollers by the single-weighted lever D. The weight of this last is regulated by means of a set-screw which turns in a nut in the jaws of the lever D, and bears upon the set-block which rests upon the journal of the top roller. This pressure is thus transmitted downwards from the top roller throughout the whole set, and at the middle roller B is added to the pressure obtained by the lever E. By this arrangement the pressure between the three under rollers is greater by the pressure of E than it is between the upper pair; but for very high pressure the lever D may be locked by set-pins, and the set-screws turned down by the hand-wheel G, until the requisite degree of pressure is obtained.

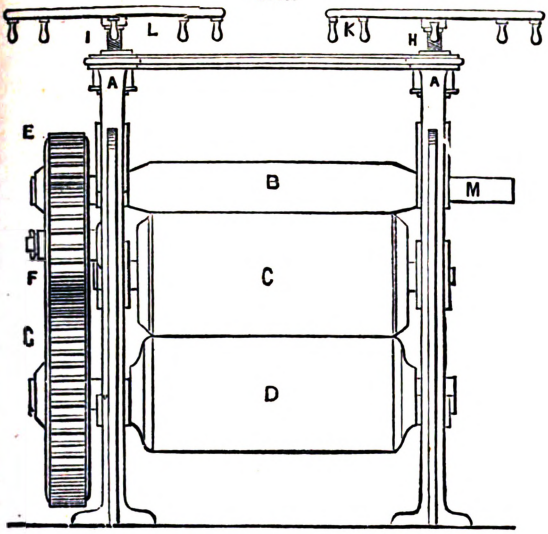
The manner of passing the cloth through this machine is the same as that already described in the calender, with this single exception, that before the cloth enters between the lower roller A and the small cylinder B, jets of water from a pipe, perforated with small holes, extending the whole width of the machine, are allowed to play upon the cloth, so as to impart to it sufficient moisture for causing it to receive the requisite degree of smoothness preparatory to the starching process, and at the same time allow the cylinder B to free it from any impurities that may be remaining in it, by forcing them back with the expressed water.

*Calender.—Description.*—A, two cast-iron frames; B C D, three cylinders, Figs. 1845, 1846; E F G, three cog-wheels; H I, two force-screws: K L, two fly-wheels with handles. The cylinder B, which is in cast iron and hollow, is heated by another iron cylinder heated red hot. The material of the cylinder C is pasteboard; its axle is of wrought iron. These three cylinders must be perfectly round and parallel.

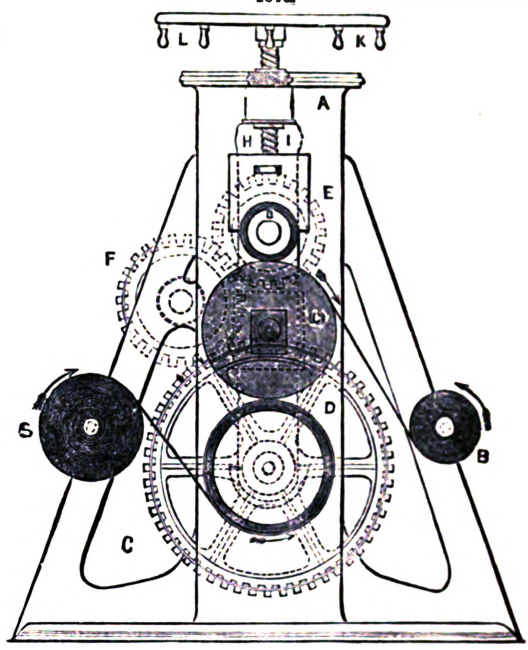
The wheel F forms the communication between E and G, which rest upon the cylinders B and D. The relation of F to the circumference of the cylinders is such that when the machine is set

to work these cylinders slide, causing friction, and thus give a gloss to the cloth. The friction is variable according to the nature of the cloth or tissue.

1845.




1846.




In order to set the machine in motion, the fly-wheels K and L being turned in order to press the screws H and I against the pillows of the first cylinder B, the cloth is placed between the rollers in the direction indicated by the arrows.

CALIPERS. Fr., *Compas, Compas d'épaisseur;* Ger., *Taster;* Ital., *Compasso da grossezze;* Span., *Compas curvo.*

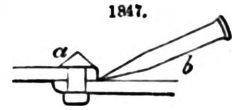
See Compasses.

CALKING. Fr., *Calfater;* Ger., *Kalfatern;* Ital., *Calfatare;* Span., *Calafateo.*

The process of copying or transferring a drawing by covering the obverse side of a design with black lead, or red chalk, and tracing lines through on a waxed plate, or wall, by pressing lightly over each stroke of the design with a point, which leaves an impression of the colour on the plate, paper or wall, is termed calking, which is often spelled *calquing.*

CALKING IRON. Fr., *Calfat;* Ger., *Das Kalfateisen;* Span., *Hierro de Calafateador ó Estopero.*

1847.




An instrument, like a chisel, used in calking ships, boilers, caissons, and so on. These little implements are of various forms, fashioned to suit different sorts of work: one form is shown in Fig. 1847; *a* the joint of the plates, *b* the tool driven by a hand-hammer. See Hand-Tools.

CALORIMETER. Fr., *Calorimètre;* Ger., *Würmemesser;* Ital., *Calorimetro;* Span., *Calorímetro.*

The apparatus invented by Lavoisier and Laplace for measuring the amount of heat contained in certain bodies is often designated as a calorimeter; this apparatus Laplace operates by the melting of ice around the body to be tested. See Pyrometer.

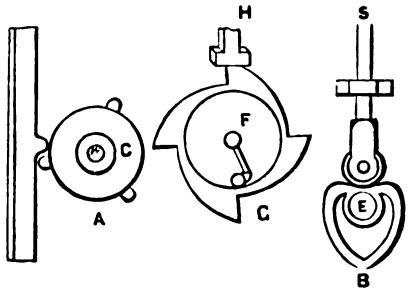
CAM. Fr., *Came,* ou *camme;* Ger., *Zahn-Daumen;* Ital., *Palmola, Dente;* Span., *Escéntrico.*

A projecting part of a wheel or other moving piece, so shaped as to give an alternating or variable motion of any desired velocity, extent or direction, to another piece pressing against it, by sliding or rolling contact. Cams are much used in machines that involve complicated and irregular movements, as in the sewing and pin-making machines.

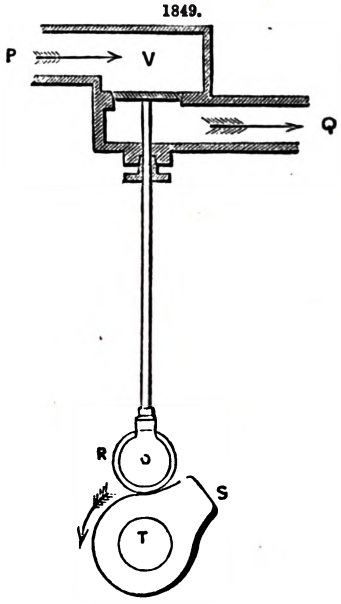
The cam-wheel A, Fig. 1848, revolving on its axis C, raises and lets fall the beam D; the heart-cam B, revolving on its axis E, gives an irregular motion to the rod S; and the cam G, revolving on its axis F, moves H, and may be made to operate an alarm bell. The cam and the toggle-joint should be considered two of the *mechanical powers;* then we should have, 1, *the lever;* 2, *inclined plane;* 3, *wheel and axle;* 4, *screw;* 5, *pulley;* 6, *wedge;* 7, *cam;* 8, *toggle-joint.* When *valves* are employed instead of slides, for altering the flow of steam to the steam-cylinder, it is usual to move them by cams. In the rough sketch, Fig. 1849, P is a pipe connected with the boiler, Q a port to the cylinder, and V a valve, which is here represented single, but it is usually of the double-beat kind, shown in Fig. 1850. The valve V, Fig. 1849, closes the passage from P to Q, the valve-rod R V, passing through a stuffing-box in the cover of the valve-box, terminates in a roller R, which bears upon a cam S, fixed on a shaft T, caused to rotate by the engine. This cam is a disc, partly circular, with part of it, S, projecting to a greater distance from the centre. As long as the roller R bears upon the circular portion, the valve V remains down upon its seat; but as the projecting part of the cam is brought by the revolution of the shaft under the roller, the valve-rod is pushed up, and the valve lifted to allow the passage of the steam. When it is desirable that the valve should be kept open during a greater or less portion of the revolution of T, the cam is sometimes made with steps of various extent, on any of which the roller may be made to bear at pleasure, as shown in plan and section, Fig. 1851. To prevent the valve being

damaged from repeated blows against its seat, a *dash-pot* is employed, which is a small cylinder, partly filled with fluid, and having a loosely-fitting piston to ease the blow of the falling weight. The stationary under-part of the dash-pot is usually filled with water, and the plunger rises and falls with the valve-stem. See Dash-Pot. In Fig. 1852 is represented the gearing for operating the steam and exhaust valves of the Ridgwood pumping engines, belonging to the Brooklyn Water Works, New York.

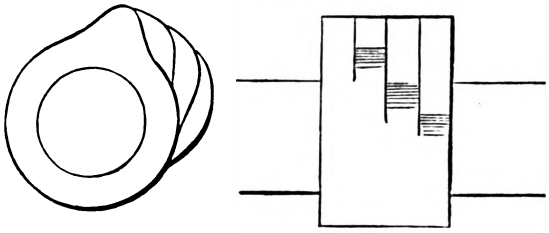
1848.




1849.

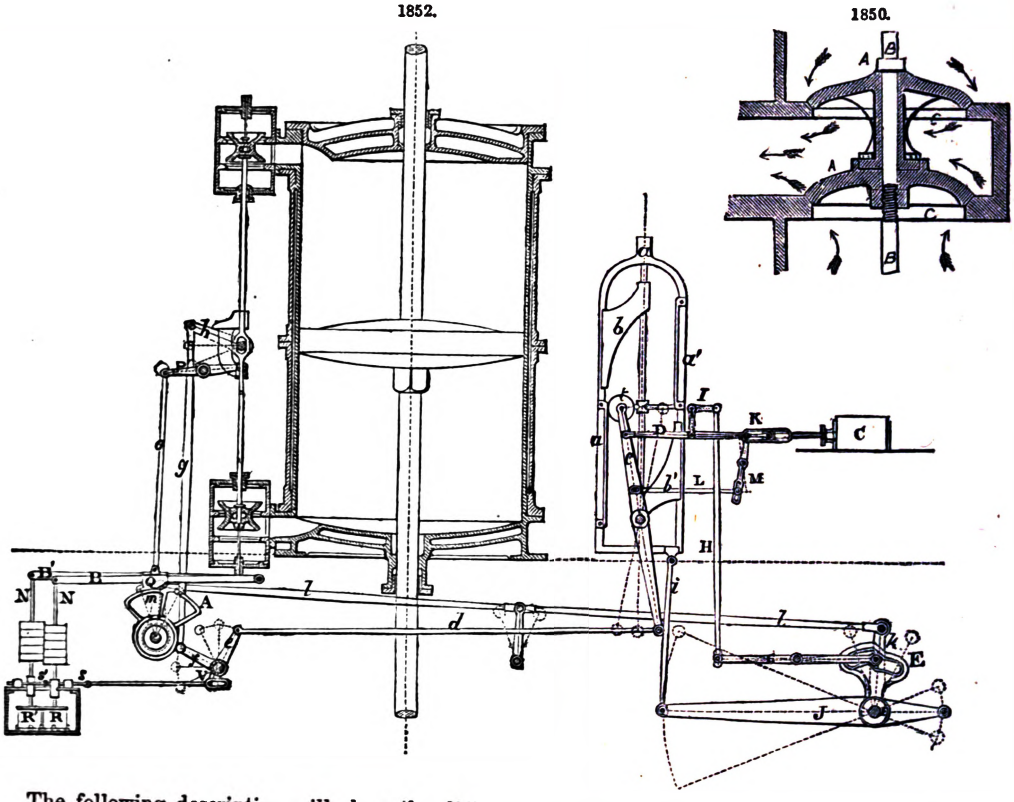



1851.



1852.

1850.




The following description will show the different functions which cams have to perform in working this gearing. The steam-piston is shown at half-stroke on its downward movement, the various parts of the gear being drawn in exact accordance with that position and direction, the upper steam and lower exhaust valves being open. The frame or yoke *a*, with the inclines *b* and *b*, on its sides, receives its motion from the beam, and moves in the same direction as the steam-

piston, and is for the purpose of closing the steam and exhaust valves; two levers *c*, with the rollers on the upper ends, transmit the motion from the inclines through the rod *d*, arms *e* and *f*, rod *g*, and arm *h*, to the exhaust-valve rock-shaft; the exhaust-valve being closed when the lever *c* has made half its movement, or on reaching its vertical position. The steam-valves are closed by the same cam-yoke *a*, through the rod *i*, lever J, arm K, rods *l*, *l*, and rock-arm or cam *m*, communicating motion to the closing-arm A of the steam-valve. The closing-arm A is in the form of a segment; the face being made of two curves, the difference in their radii being equal to the lift of the steam-valve: this segment or cam is adjustable by hand, that is, the closing-face can be brought sooner or later under the toe of the lever B or upper steam-valve, performing the closing or "cut off" at the point required. The *water-cylinder* C is used exclusively for *opening* the steam and exhaust valves, and is furnished with a piston, admission and exhaust ports, valves, &c., like any steam-cylinder. The piston-rod is attached to a cross-head, and connected to the levers *c*, by the rod D. The admission and exhaust valve are operated from the double-curved arm or cam E, on the rock-shaft E. The slot in the arm E is composed of two curves joined together in the vertical centre by an inclined slot; the difference in the radii of the curves being equal to the movement of the valve, and the length of the incline determines the time of action. On the end of the lever G is a roller revolving freely on a journal, and fitting the slot on the arm E, the vibrating motion of the arm raising or depressing the roller from one curve to the other, imparting a like motion to the other end of the lever G, and through the rod H and right-angled arm I to the valve-rod K. It will be observed that this valve motion is intermittent. There is another valve in the *water-cylinder chest* which we call the supply-valve; as it opens and closes the communication between the water-chest and the rising main, and is operated from the roll-lever *c*, through the connecting-rod L and lever M, attached to the valve-rod; this motion to the supply-valve is also intermittent, and made by the slot in the rod L and lever M. The ends of the lower levers B, B′, of the steam-valves are connected to weighted plungers N, N′, working in small open cylinders, or *dash-pots* R′, R′, one for each valve; the gravitation of the weighted plungers opens the steam-valves through the rods O and lever P, attached to the valve-stems, and the time taken to open the valve wide being regulated by the velocity of the water forced out of the dash-pots, a small cock being fitted to each for this special adjustment. This completes the description of the various parts of the gearing and their separate duties; we shall now show the combined action of the whole in relation to the steam-piston.

The steam-piston having reached midway on its downward stroke, of course the frame or yoke *a* is also at mid-position in the same direction, and the upper steam-valve open—its weighted plunger unlatched and at the bottom of the cylinder; the lower exhaust-valve is also open, leaving free communication between the under-side of the steam-piston and the condenser. These are positions of the parts as illustrated in Fig. 1852. Now, as the cut off usually takes place at or about half-stroke in this engine, it will be seen, by reference to the figure, that the closing part on the periphery of the arm A is just entering under the toe or cam Q of the lower lever or upper steam-valve; and very little more movement of the arm A will close the valve—that is, the lower will be lifted by the action of the arm, transferring its motion through the rod O and lever P to the valve-stem, forcing it downward and closing the valve, at the same time the lower lever B on its lift is carried with its weighted plunger to the top of its dash-pot R. The latch-bolt *s*, shown in the figure as withdrawn, enters a socket in the plunger by the action of a spring on its back, and holds the plunger there until it is time to open the upper steam-valve again on its next downward stroke; the closing-arm A moves on without producing any further motion to the lower lever B, its toe simply resting on the curve of the arm as it passes under it. The steam-valve being now closed, the balance of the down-stroke is made by the exhaust steam; the frame or yoke *a* is descending, and the water-cylinder piston C is at full stroke towards the steam-cylinder; the admission-valve K of the former has just accomplished its half-movement, that is, it is square over its cylinder ports. When the frame or yoke *a* has descended so that the lower end of the upper incline *b* comes in contact with the roller *t*, on the lever *c*, the water-cylinder valve K has completed its movement, opening the back port to the exhaust passage, and removing the water on the back of the piston, and leaving the front port open ready for the admission of pressure on the front side of the piston. The motion of this admission-valve ceases now, or at least until the frame *a* has arrived at the same position on the up-stroke, when a similar but a reverse motion takes place. This cessation of motion to the admission-valve is accomplished by the rock-arm E having moved its curved slot or cam over the roller, the movements to the valve attachments being produced while the inclined part of the slot is passing under the roller of the lever G. The frame or yoke *a* is still descending under the operation of the expanding steam; the upper incline *b* has forced the lever *c* over its vertical position or half-movement, closing gradually the lower exhaust-valve through the various connections, rock-arms, and toes. The duty of the upper incline *b* ends here for the down-stroke; at the same instant the admission-valve covering the supply port between the water-cylinder chest and rising main is opened by the action of the rod L and lever M, and water under pressure admitted to enter the already open port of the water-cylinder, carrying the water-piston to the end of its stroke, and with the lever *c*, through the connecting-rod D, which movement opens the upper exhaust-valve, and permits the steam that has just expended its power on the down-stroke to escape to the condenser; by this same movement the short arm V comes in contact with the end of the slot in the latch-bolt of the lower steam-valve, withdrawing it, and allowing the lower steam-valve to be opened by the gravitation of the weighted plunger N, through similar rods, levers, and so on, as described for the upper steam-valve. The engine is now reversed and commencing its upward stroke; but the direction reversed, the lower incline *b*, on the frame *a*, performing a similar duty on the upper stroke as the upper one did on the down-stroke, and so on continually. In such movements cams perform important operations. See Bank-note Printing Machine. Battery. Brick-making Machines. Mechanical Movements. Pin-making Machines. Press. Sewing Machines.

## CAMERA LUCIDA.

The camera lucida is a little bit of peculiarly-shaped glass, placed on a prop, and it enables any person, although that person be ignorant of the rules of perspective and but little accustomed to make drawings, to take with a pencil or pen on paper the lines and shades of any machine or other object with ease and accuracy.

This useful little instrument, conveniently mounted for use by Elliott Brothers, 449, Strand, is shown in Figs. 1853, 1854; the small four-sided glass prism is set at K.

Fig. 1856 is an enlarged section of this prism at right angles to the edges. A is a right angle, and B an angle of 135°. The angle at the eye and the one opposite are equal; each of those angles must therefore be equal to 67½°:

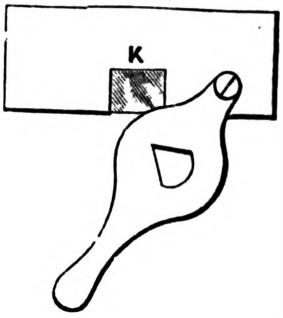
$$135 = 90 + \frac{90}{2}, \text{ and } 67\tfrac{1}{2} = 45 + \frac{45}{2}.$$

The bit of glass, or glass prism, which is not much larger than a thumb-nail of ordinary size, is held in a brass frame K, Fig. 1855, which is attached to an upright rod, having at its lower end a screw clamp, to fix it to the edge of a drawing-board or table, Figs. 1853, 1854. The prism K is fixed at the height of about 10 or 12 in. from the table, and has its upper face, A, Fig. 1856, that is K, 1855, nearly horizontal. Rays coming from an object, R S, Fig. 1856, and falling nearly perpendicular on the first surface, enter the glass prism, and undergo total reflection from the contiguous surface, then they fall at the same angle on the next surface, and are totally reflected again; lastly, they emerge nearly perpendicular to the horizontal surface, as represented in Fig. 1856. The eye receives the emergent rays, and perceives the image *r s*, with all the shades,

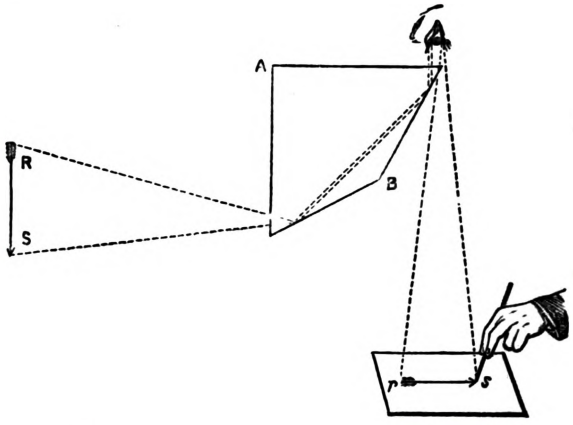
1853.

1854.

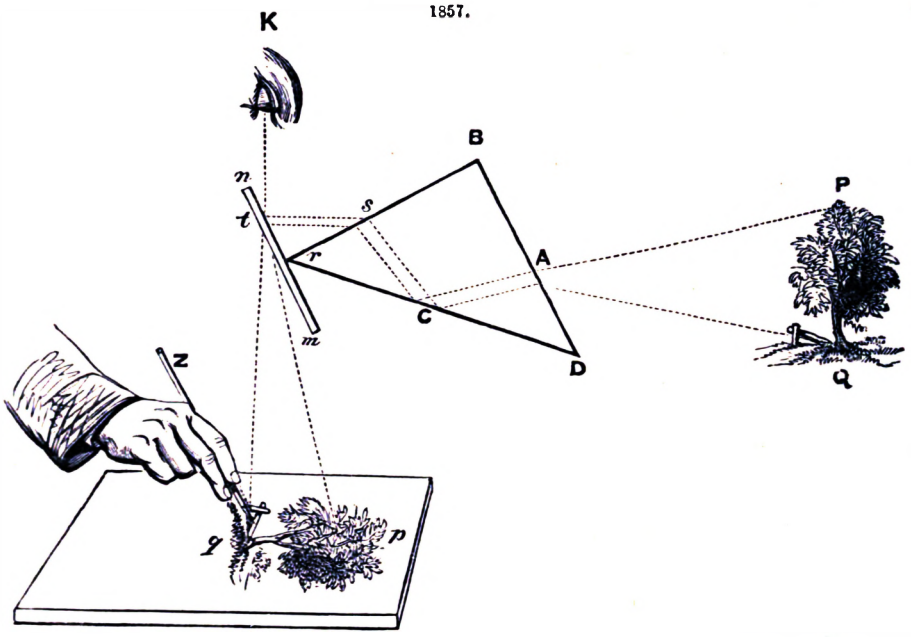
1855.




856.




1857.




lines, and colours of R S, on a sheet of paper upon a drawing-board or table to which the instrument is made fast. If the lines of the image are traced with a pencil, a very correct design

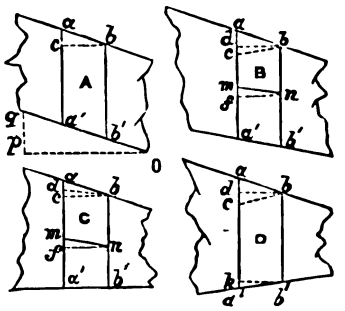
is obtained; but there is some difficulty in seeing both the image and the point of the pencil, for the rays from the object give an image which is farther from the eye than the pencil. This difficulty is readily surmounted by a little practice, and by placing between the eye and the prism a lens, which gives to the rays from the pencil and those from the object the same divergence. In this case, however, it is necessary to place the eye very near the edge of the prism, so that the aperture of the pupil is divided into two parts, one of which sees the image, and the other the pencil. The arrangement of the horizontal face, Fig. 1855, effects this object to the greatest nicety. Amici's camera lucida, represented in Fig. 1857, is preferable to that of Wollaston, Fig. 1856, inasmuch as it allows the eye to change its condition to a considerable extent, without ceasing to see the image and the pencil at the same time. It consists of a triangular glass prism, B D $r$, right angled at B, having one of its perpendicular faces B D turned towards the object P Q that has to be drawn at $p\,q$; the other side of the prism B $r$ is placed at right angles to an inclined plate of glass, $n\,m$. The rays P Q A, proceeding from the object, and, entering the prism, are totally reflected from the base at C, and emerge in the direction $s\,t$. They are then partially reflected from the glass plate $m\,n$ at $t$, and form a vertical image of the object P Q, which is seen by the eye in the direction $t\,p\,q$. The eye, at the same time, sees through the glass $m\,n$, the point of a pencil applied to the paper, and the outline of the object may be traced: when straight lines have to be traced, a ruler can be applied.

CANAL. Fr., *Canal*, Ger., *Kanal*; Ital., *Canale*; Span., *Acéquia*, *Canal*.

1. Canals differ in this regard from rivers, that they have a regular bed, having throughout the same inclination and the same profile; and they carry down the same volume of water throughout their length. In case one of these conditions is not fulfilled, where, for instance, after a certain slope, another is assumed, there will result two canals, the one succeeding the other.

If from the point $o$, Fig. 1858, at the bottom of the canal, a horizontal line $o\,p$ is drawn, its corresponding vertical $q\,p$ will be the slope of the canal for the length $o\,q$. It is called the *absolute slope*, if $o$ and $q$ are the extremities of the bed of the canal; and the *relative slope*, or the slope per foot, if $o\,q$ is 1 ft. long. Calling the slope $p$, if L is taken for any length of a canal, D being the difference of level between the extremities of this portion, we have $p = \frac{D}{L}$; or, if $e$ represents the angle of inclination $p = \sin.\ e$.

1858.




The *section* of a canal, or any water-course, is the area of the section made by a plane perpendicular to the axis of the current; in a rectangular canal, if $l$ = breadth and $h$ = depth, $s$, or area of section, is $s = l\,h$; if it is trapezoidal, $l$ = breadth at bottom, and $n$ the slope of the sides, or the ratio of the base to the height, then $s = (l + n\,h)\,h$ or $s = (l + \cos.\ f.h)\,h$, where $f$ is the inclination of the sides to the horizon.

That part of the contour of the fluid section in contact with the bed or bottom, as well as sides or berms, is called the *wetted perimeter* of the section. Designating it by $c$ for rectangular canals, we have $c = l + 2\,h$; for trapezoidal, $c = l + 2\,h\sqrt{n^2 + 1} = l + \frac{2\,h}{\sin.\ f}$.

Dubuat gives the name of *mean radius* of the section, for the ratio of the area to that of the *wetted perimeter*, or $\frac{s}{c}$.

Let us now examine the nature of the motion of water in canals, that is to say, the nature and expression of the forces which produce it; thus establish the formulæ of this motion, with their various applications; and, finally, ascertain the quantity of water which canals can receive at their heads or inlets.

2. *Nature of Motion in Canals.*—Gravity is the sole force that acts upon a mass of water left to itself, in a bed of any form; it produces all the motion which takes place.

Whenever its action upon each fluid particle (whether it be that which it exerts directly downwards, or that indirectly produced by the lateral pressure of the adjoining particles) is destroyed, so that the fluid mass is brought to a state of rest, its surface will be horizontal. Reciprocally, when the surface of a fluid is horizontal, exception being made for any impulse before impressed upon it, all action of gravity will be destroyed, and no motion can take place. But as soon as this surface is inclined, motion takes place, and continues, even if the bottom of the bed is horizontal, and even if it should have a counter-slope for some distance. Whence the principle, admitted in hydraulics, that *the motion of particles in a water-course is due wholly to the slope at the surface; this* slope it is which is the immediate cause of motion, and enables gravity to act.

3. Let us examine the mode of action of this force, and what is its measure in the different cases that may occur, which are represented in Fig. 1858.

Suppose, then, a canal, in which the surface of water is parallel to the bottom of the bed, and consider the very small section A. The fluid particles which are on the bottom $a'\,b'$, will descend by the direct action of gravity, as down an inclined plane. Those which are above, up to the surface $a\,b$, forming, as it were, threads laid upon the first, will descend in the same manner. The effective portion of gravity, that which is not destroyed by the resistance of the bed, and which causes the motion, will be represented by the height $a\,c$, and this height will be $g$ sin. $i$; $i$ being the inclination of the surface $a\,b$ to the horizontal $b\,c$. The indirect action of gravity, or the lateral pressure experienced by each particle, being the same in all directions, by reason of the parallelism of $a\,b$ and $a'\,b'$, will not occasion any motion.

Let us admit, now, a current with a surface more inclined than its bed, and represent a small

section of it by B. Take, then, into consideration, any particle, $m$, traversing the section in the direction $m n$. This particle, or rather the linear system of particles $m n$, will experience: 1st. The direct action of gravity, which we represent by the height $m$ of the inclined plane $m n$, or by its equal $c d$, $m d$ being taken equal to $n b$. 2nd. The indirect action due to the inequalities of pressure upon the two extremes of the system $m$ and $n$; at the upper extremity $m$, conformably to the rules of hydrostatics, the pressure is represented by the height of the fluid column $m a$; at the lower extremity it is represented by $n b$; the resultant of these two pressures, that which produces motion, will equal then $m a - n b = a d$: as for the pressures which each particle of the system experiences at its sides, perpendicular to $m n$, they will be equal to each other, and reciprocally destroy each other, and have no effect. Thus the system $m n$ will be urged downwards by the two forces $a d$ and $c d$, or by their sum $a c$, which is $g$ sin. $i$, $i$ being the inclination of the surface.

When the bed is horizontal, as in the section C, the direct action of gravity upon the particles in contact with the bottom will, it is true, be entirely destroyed by the resistance of the bottom; but the indirect action, or the inequalities of pressure, will amount to $a a' - b b' = a c = g$ sin. $i$. For all other particles $m$, the moving force will be as above, $m f + (m a - n b) = c d + d a = a c = g$ sin. $i$.

Finally, if the bottom has a counter-slope, as in D, the particles upon it will be urged back or up stream, by its relative gravity, $k a' = c d$; but, on the other hand, they will be urged downward by the difference of the pressing columns $a a'$ and $b b'$, or by $a d$. Hence it follows that they will be impelled in this last direction by $a d - c d = a c = g$ sin. $i$.

4. It follows, from these different facts, that, in a water-course of any form, each particle, in traversing a section having an inclination of surface equal to $i$, receives from gravity an impulse represented by $g$ sin. $i$; that is to say, that if the impulse continues during one second, it will produce a velocity equal to $g$ sin. $i$; this, then, is the expression of the accelerating force, and is dependent solely upon the indication of the surface.

This slope, so to speak, may vary at every step, or it may be constant for a long space, in which case a longitudinal section of the surface of the current forms a right line. This is frequently the case in canals, properly so called, of a constant slope and profile; the surface lines and the bottom lines can neither converge nor diverge, and must be parallel; the surface will then have the same inclination as the bottom, and the sin. $i$ will be = sin. $e$, or = $p$ (2), and the accelerating force will be = $g p$.

5. From what has been said, water running in a canal is constantly subject to the action of an accelerating force; so that, if it encounter no other opposing force, it will descend with an accelerated motion, and its velocity would never be uniform. Nevertheless, it often attains this uniformity in a very short space of time, after which the acceleration is inappreciable. Experience proves this to be a fact; it is to be seen in most canals, even those of great slope. Thus Bossut, causing water to run in a wooden canal 656 ft. long, with a slope of 1 in 10, and having divided the canal into spaces of 108 ft. each, has found that each division, excepting the first, has been traversed in the same time. There must then be, after a certain period of time, a retarding force, which destroys at each instant the effect of the accelerating force, and which is equal to it. Thus, water will move along with a velocity acquired in the first moments of its running; a phenomenon similar to that produced in nearly all motion; in that of machines, for example.

But in canals there can be no retarding force but that which comes from the resistance of the bed. This resistance cannot be called in question; from experiments made with a tube 2·06 ft. long, there was a discharge of 5·22 cubic ft. in 100″; and when its length was doubled to 4·12 ft., dimensions in other respects the same, it took 117″ to discharge the same volume. Thus the velocity in the tube was diminished in the ratio of 117 to 100; and it can only be that the canal, by reason of its increased length, offered a greater resistance to the velocity; it therefore resisted motion.

6. Let us examine the nature of this resistance.

When water passes over the surface of a body, there being no repulsion or negative affinity between the two substances, it wets this surface; that is to say, a thin lamina of fluid is applied to it, penetrating its pores, and it is retained there, both by this engagement of its particles, and by the mutual attraction of the particles for each other.

It is over such a revetment or watery covering, fixed against the sides of the canal, that the water which it conducts must pass. The thin sheet of this mass, immediately in contact with this covering, by sliding along and rubbing against it, mingles its particles with those of the covering —it adheres, and its velocity is retarded. In consequence of the mutual adhesion of the particles, this stoppage, gradually diminishing, is communicated from one to another of the adjacent layers, till it is felt by the most distant fillets. The mass, in consequence, receives a mean velocity less than would take place without the action of the sides and the viscosity of the fluid.

The cause of this diminution of velocity has often been attributed to the friction of the water against the sides of its bed. Such a friction, if it occurs at all, is of a nature entirely different from that of solid bodies against each other; it depends neither upon the pressure nor the nature of the rubbing-surfaces. Dubuat is convinced, by direct experiments, that the *resistance of water is independent of its pressure.* He has never yet found *any variation in the friction of water upon glass, lead, pewter, iron, woods, and different kinds of earth.*

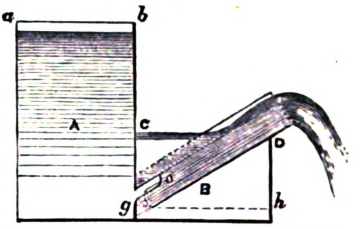
This last fact might be accounted for by observing that in all cases the friction can only take place upon the aqueous layer which covers the sides of the bed. But a friction independent of pressure? It would seem quite natural to admit that the resistance could proceed from no other source but the adhesion of the particles of water in motion, both among themselves and with those of the fluid-covering of the sides of the bed.

This adhesion has been measured by weights. Dubuat found that, to detach tin plates from tranquil water with which they had been brought in contact, there was needed, beside their own weight, an effort of 0·96 lb. avoirdupois to 1·03 lb. the square foot of surface.

Venturi, by means of a remarkable experiment, affords a direct evidence of the effect of adhesion,

which enables the particles of water in motion to catch up and carry in their train those which are contiguous to them in a fluid mass at rest. To a reservoir A, Fig. 1859, kept constantly full, was fastened a box filled with water, in which was placed a trough C D, open at its ends, and its bottom resting on the edge D. A small tube was placed in the reservoir, with its end at O. As soon as this was opened, the jet which issued, passing through the water which had found its way into the trough, drew with it the part adjacent; this was replaced by that immediately next it, which in its turn was replaced by the water in the box; so that, in a short time, the water fell from the level of $q$ D to $g h$.

1859




7. Since the resistance is from the action of the sides of the bed, the greater the extent of these sides, that is to say, the greater the *wetted perimeter* for any unit of length, the greater the amount of resistance.

But this resistance of the perimeter will be shared among all the particles of the section, since their motion is connected by a mutual adhesion; thus, the greater the number of particles, or the greater the section, the less will the velocity of each, and consequently their mean velocity, be changed. The effect of resistance will be in the inverse ratio of the section.

On the other hand, the resistance will increase with the velocity. The greater this is, the greater will be the number of particles drawn at the same time from their adhesion to the sides; and, further, it must draw them more promptly, and consequently expend more force; so that the resistance will be in the double ratio of the velocity. The viscosity of the fluid occasions still another resistance, which becomes more sensible, compared to the first, as the velocity is smaller. Dubuat has observed this important fact, and Coulomb, through a series of experiments, found that it is simply proportional to the velocity. Thus the expression of ratio between the resistance and velocity involves two terms; in one, the velocity is as the second power; in the other, as the first; this last, which is but a small fraction of the velocity, will disappear in great velocities; it is always inferior to the other, when the velocity exceeds 0·23 ft., but below this it preponderates. In short, the resistance experienced by water from its motion in a canal, is proportional to the wetted perimeter, to the square of the velocity, plus a fraction of velocity, and is in the inverse ratio of its section. Experience proves that this is very near the truth.

With the symbols already adopted, in calling $b\,v$ the fraction of the velocity in question, and $a'$ a constant multiplier, the expression of resistance will be $a' \frac{c}{s} (v^2 + b\,v)$.

8. After what has just been said upon the resistance of the bed and its effects, the different fillets of a fluid in motion in a canal will have a velocity the greater as they are removed from the sides of the bed; thus they will have different velocities. Nevertheless, in estimating the discharge of a canal, we may admit that the whole mass of water in motion is endowed with a mean velocity; which will be such as, being multiplied by the section of the canal, will give the volume of water passed in one second. So that if Q represents this volume, $s$ being the section and $v$ the mean velocity, we have $Q = s\,v$.

9. From what has been stated above, it follows that the greatest velocity of a current will be at its surface—in its middle, if the transverse profile is regular—if it is not, then in portions very nearly corresponding with the greatest depths; it is there that is generally found the *thread of water*, or fillet of the greatest velocity.

This velocity of the surface, being that most easily determined by experiment, the knowledge of its ratio with the mean velocity is a subject of great interest in practice; it will enable us to determine this last velocity so as easily to calculate the discharge. The investigation of this ratio has been the object of many hydraulic observers, as we shall see in the article on Rivers; we confine ourselves here to what concerns canals.

Dubuat has made precise experiments upon this subject. They are in number thirty-eight. They were made with two wooden canals 141 ft. in length; the one of a rectangular form 1·6 ft. wide—the section of the other a trapezium whose small base was ½ ft., with its sides inclined 36° 20' to the horizon (making $n = 1{\cdot}36$); the depth of water varied from 0·17 ft. to 0·895 ft., and the velocity from 0·524 ft. to 4·26 ft. Dubuat concludes, from these experiments, that the ratio of velocity at the surface, to that of the bottom, is greater according as the velocity is less, and that this ratio is entirely independent of the depth; that to the same velocity of surface corresponds the same velocity of bottom. He has observed also that the mean velocity is a mean proportional between that of the surface and that of the bottom. Calling $u$ the velocity of the bottom, V that of the surface, and $v$ the mean velocity, he gives the results of his observations by the formula

$$u = (\sqrt{V} - {\cdot}298868)^2 \text{ and } v = \frac{V+u}{2} = (\sqrt{V} - {\cdot}149434)^2 + {\cdot}022332.$$

Prony, after discussing the experiments of Dubuat, has thought this the more convenient formula, $v = V \frac{V + 7{\cdot}78188}{V + 10{\cdot}34508}$.

Here is a small Table of some values of $v$ corresponding to values of V, as given by this formula. Prony, taking a mean term, has thought that, in practice, we may take $v = 0{\cdot}8\,V$; that is to say, in order to have the mean velocity of a current of water, we may diminish that of the surface one-fifth.

| V. | V. | v. |
|---|---|---|
| mètres. | feet. | |
| 0·25 | ·8202 | 0·77 V |
| 0·50 | 1·6404 | 0·79 V |
| 1· | 3·2809 | 0·81 V |
| 1·50 | 4·9213 | 0·83 V |
| 2· | 6·5618 | 0·85 V |

10. *Formulæ of Motion.*—We have two kinds of motion to consider. Most frequently, the surface of a current in a long and regular canal

assumes a constant slope, which is the same as that of the bottom of the bed, and this surface becomes parallel to this bed. Then all transverse sections are equal; the mean velocity is the same in each, and the *motion is uniform*.

But it often happens that the surface varies from point to point, and is not the same with that of the bottom; so that, at different points of the canal, the sections, and consequently their velocities, are no longer equal. Still, the quantity of water admitted in the canal remaining the same, upon each isolated point, the section of the fluid mass will be constantly the same, and the velocity then will always have an equal value: all, then, is constant, and the motion, without being uniform, *will be permanent*.

11. *Uniform Motion.*—We have already remarked that, when the water in a canal becomes uniform, the retarding force equals the accelerating force; and that the expression for this last, in such kind of motion, is $gp$; so that we have $gp = a' \frac{c}{s} (v^2 + bv)$; or, making $\frac{a'}{g} = a$, we have

$$p = a \frac{c}{s} (v^2 + bv).$$

If, at a portion of the canal where the motion is uniform, we take two points upon the surface of the fluid, whose distance apart we represent by L', and difference of level or absolute slope by D, we have $p = \frac{D}{L'}$, and $D = a \frac{cL'}{s} (v^2 + bv)$. If we take the canal throughout its entire length, which we called L, and H being the difference between the head and foot of the same; from this difference H, we must take a height due to the velocity $v$ of uniform motion, and it will be presently shown (27) that $H - \frac{v^2}{2g} = a \frac{cL}{s} (v^2 + bv)$.

12. It remains to determine the two constant coefficients $a$ and $b$.

Prony, in combining the results of thirty experiments made by Dubuat, has undertaken and executed this determination. Some years afterwards, Eytelwein following the steps of Prony, but extending his observations upon ninety-one canals or rivers, in which the velocity varied from 0·407 ft. to 7·94 ft., and the fluid section from ·151 sq. ft. to 28·030 sq. ft., found $a' = ·0035855$, or $a = ·000111415$, and $b = ·217785$, the English foot being the unit.

Thus, putting for $g$ its value = 32·18 ft., the fundamental equation for the motion of water in canals will be $p = ·000111415 \frac{c}{s} v^2 + ·0000242647 \frac{cv}{s}$; or, observing that $v = \frac{Q}{s}$ (8), Q being the discharge, $ps^3 = ·000111415\, c\, Q^2 + ·0000242647\, c\, Q\, s$. Of the four quantities, Q, $p$, $s$, and $c$, or, remembering that $s = (l + nh)$, $h$ and $c = l + 2h(\sqrt{n^2 + 1})$ (1), of the four quantities, Q, $p$, $h$, and $l$, three being given, this equation enables us to ascertain the fourth. As for $n$, the slope to be given to the banks, it will be indicated by the nature of the soil in which the canal is dug.

13. It is seldom that the velocity is found among the list of problems to be resolved; still, for any case where its direct expression is required, the first of the two equations above gives

$$v = -0·1088946 + \sqrt{8975·414 \frac{ps}{c} + ·01185803};$$

or, more simply, and with sufficient accuracy, $v = \sqrt{8975·414 \frac{ps}{c}} - 0·1088946$.

14. Consequently, we have from $Q = sv$,

$$Q = s\left(-0·1088946 + \sqrt{8975·414 \frac{ps}{c} + ·01185803}\right), \text{ or}$$

$$Q = s\left(\sqrt{8975·414 \frac{ps}{c}} - ·1088946\right).$$

15. In great velocities, those of 3·2809 ft., for instance, or any above this, where the resistance is simply proportional to their square, we have

$$v = 94·738 \sqrt{\frac{ps}{c}}, \text{ and } Q = 94·738\, s \sqrt{\frac{ps}{c}}.$$

Let there be, for example, a canal, whose section is a trapezium 13·124 ft. wide at top, 3·2809 ft. at bottom, and 4·92 ft. deep; with a slope of 0·001. Required, the quantity of water which it will convey.

We have $p = 0·001$; $l = 3·2809$ ft.; $h = 4·9214$ ft. With regard to $u$, or ratio of base to height of banks, the height is that of the trapezium, and the base is one-half the difference between the two bases; so that $n = \frac{13·124 \text{ ft.} - 3·2809 \text{ ft.}}{2 \times 4·9214} = 1$. From this, $s = (l + nh)\, h = (3·2809 + 4·9214)\, 4·9214 = 40\ 366$ sq. ft.; and $c = l + 2h\sqrt{n^2 + 1} = 17·2$ ft. Consequently, Q, the quantity sought, is

$$Q = 40\ 366\left(\sqrt{8975·414 \frac{40·36 \times ·001}{17·2} + ·01185805} - ·108895\right) = 180·87 \text{ cub. ft.}$$

If we neglect the term ·01185805 under the radical, we have for Q = 180·843, which only differs from the above by ·027.

The formula above for great velocities would give

$$Q = 94{\cdot}738 \times 40{\cdot}366 \sqrt{\frac{{\cdot}001 \times 40{\cdot}366}{17{\cdot}2}} = 180{\cdot}65 \text{ cub. ft.}$$

16. The slope is directly given by the fundamental equation which we have already established (12).

The Canal de l'Ourcq furnishes both an example of the mode of its determination, and some remarks worthy of attention.

There were 106·61 cub. ft. of water a second to be disposed of; the projected navigation required there a depth of 4·9214 ft.; and in order that the water should always be at hand for the service of the fountains in Paris, it was necessary that it should have at least a velocity of 1·1483 ft.; the soil was such as to admit of a slope of 1½ base to 1 of height.

We have, then, $Q = 106{\cdot}61$ cub. ft.; $v = 1{\cdot}1483$ ft.; $h = 4{\cdot}9214$ ft.; and $n = 1{\cdot}50$. Moreover, from the given terms of the problem, $s$ is known, for $s = \frac{Q}{v} = \frac{106{\cdot}61 \text{ cub. ft.}}{1{\cdot}1483 \text{ ft.}} = 92{\cdot}843$ sq. ft.; $l$ will also be known, since from the expression $s = (l + n\,h)\,h$, we deduce

$$l = \frac{s - n\,h^2}{h} = \frac{92{\cdot}843 - 1{\cdot}50 \times 4{\cdot}9214^2}{4{\cdot}9214} = 11{\cdot}483 \text{ ft.};$$

consequently, we have $c = l + 2\,h\sqrt{n^2 + 1} = 29{\cdot}227$ ft.; whence the general equation,

$$p = {\cdot}0001114155\,\frac{v^2\,c}{s} + {\cdot}000024265\,\frac{v\,c}{s};$$

substituting the numerical quantities, gives $p = 0{\cdot}00005502$: such is the slope indicated by the formulæ.

Girard, the engineer who planned the canal, arrived at very nearly the same result. But he has observed, with reason, that aquatic plants, growing always upon the bottom and berms of the canal, augment very much the wetted perimeter, and consequently the resistance; he remembered that Dubuat, having measured the velocity of water in the canal (du Jard) before and after the cutting of the reeds with which it was stocked, has found a result much less before the clearing. Consequently, he has nearly doubled the slope given by calculation, and has carried it up to 0·0001056; the length of the canal being 314966 ft., this gives 33·260 ft. of absolute inclination.

17. If the dimensions $l$ and $h$ were the one unknown, and the other one of the given quantities of the problem to be solved, we take the values of $c$ and $s$ as functions of these two dimensions, and substitute them in the fundamental equation (12); $l$ would then be deduced by the resolution of an equation of the third degree, and $h$ by that of an equation of the fifth degree.

Let us determine, for example, the width to be given at the bottom of a canal, appointed to conduct 123·60 cub. ft. of water, with a depth of 4·9213 ft., the slope being 0·0001, and the soil of such a character as to require for slope the base to be twice the height. Thus, $Q = 123{\cdot}60$ cub. ft.; $p = 0{\cdot}0001$; $h = 4{\cdot}2649$ ft.; and $n = 2$.

We substitute these two last quantities in the expressions of $s$ and $c$ (1), which in their turn are substituted in the general equation. This will involve, then, only the unknown term $l$; and, making all reductions, and arranging according to the powers of $l$, we have

$$l^3 + 23{\cdot}943\,l^2 - 46{\cdot}578\,l - 3832 = 0.$$

Substituting for $l$, we find, on trial, $l = 11{\cdot}138$ ft.

18. Most generally $l$ and $h$ are not given terms of the problem; we have only Q and $p$, or the volume of water which the canal ought to conduct, and the slope which it should have, leaving the engineer to determine the width and depth. To obtain these two unknown quantities, there is but one equation; the problem, therefore, is indeterminate. The engineer then supplies the gap, in giving such a figure as he deems best adapted to the profile of the projected canal; this figure, indicating the relation between the two dimensions, furnishes the equation which was hitherto needed.

In the choice of this figure, regard must be had to the object most important to be fulfilled, and that that is adopted which fulfils it with least expense of construction and of maintenance. When it is desired to convey the greatest possible quantity of water to the point where the canal empties, according to the formula of discharge (14 and 15), the volume of water brought down is so much the greater, as the section of the fluid mass is greater, and as the wetted perimeter is smaller; consequently, we must take a figure which, with the same perimeter, presents the greatest surface.

19. Geometry informs us that the circle has this property. The semicircle, and therefore a semicircular canal, has the same property, the ratio between the semicircle and semicircumference being the same as that between the circle and entire circumference.

Then follow the regular demi-polygons, and with the less advantage, as the number of their sides is less; and so among the most practicable forms we have the regular demi-hexagon, the demi-pentagon, and finally the half-square.

But these figures are not admissible for canals in earth excavations; their berms, not having sufficient slope, would cave in.

In order that they should be sustained without revetment, they should have a slope of from 1·50 to 2 of base to height, as there is more or less consistency in the soil; in the regular semi-hexagon, where the slope is larger than the other named polygons, it is only 0·58. A slope of 1 is only adopted in excavations of small importance or for temporary use; but for canals, the slope of 2 to 1 is usually adopted, and sometimes 2½; such was the slope adopted at the canal of Languedoc.

20. As the usual profiles of canals are trapezoidal, the question of figure of greatest discharge is reduced to taking, among all the trapeziums with sides of a determinate slope, that which yields the greatest section for the same wetted perimeter.

Since the section $s$, or $(l + n h) h$, should be a *maximum*, its differential will be zero, and we have $h d l + l d h + 2 n h d h = 0$.

Since the perimeter remains constant, the expression $c = l + 2 h \sqrt{n^2 + 1}$ (1) being differentiated, gives us $0 = d l + 2 d h \sqrt{n^2 + 1}$. The value of $d l$, derived from this equation and substituted in the preceding, gives $l = 2 h (\sqrt{n^2 + 1} - n)$.

With this value of $l$, we have $s = h^2 (2 \sqrt{n^2 + 1} - n) = n' h^2$, by making $2 \sqrt{n^2 + 1} - n = n'$; and $c = 2 h (2 \sqrt{n^2 + 1} - n) = 2 n' h$.

Putting these equivalents of $s$ and $c$ in the fundamental equation of motion (12), it becomes

$$\frac{p n'^2 h^5}{2} = 0{\cdot}0001114155\, Q^2 + 0{\cdot}0000242651\, Q n' h^2.$$

This and the preceding equation give for $l$ and $h$ the *maximum* sought.

Let us take, for example, $Q = 70{\cdot}6632$ cub. ft., $p = {\cdot}0012$, $n = 1{\cdot}75$. The second of the above equations is reduced to $h^5 - 1{\cdot}2522\, h^2 - 178{\cdot}04 = 0$.

Making, by a first approximation,

$h = 2{\cdot}82$ ft., we have .. .. .. .. .. $- 9{\cdot}6593 = 0$.
$h = 2{\cdot}85$ ft. .. .. .. .. .. .. .. $- 0{\cdot}1821 = 0$.
$h = 2{\cdot}850567$ ft. .. .. .. .. .. .. $+ 0{\cdot}0002 = 0$.

So that the true value of $h$ will be $2{\cdot}850567$ ft. This will give for $l$, which is $2 h (\sqrt{n^2 + 1} - n)$, $= 1{\cdot}5107$ ft.

These dimensions are those of the stream. But the depth of the excavation should be greater. It would be well to increase it to .. .. .. .. .. .. .. .. .. .. 3·937 ft.
The breadth at bottom remains the same .. .. .. .. .. .. .. 1·5105 ft.
The breadth at level of earth will be .. .. .. .. .. .. .. .. 15·29 ft.
There will then be, a running foot of cut, an excavation of .. .. .. 33·1 cub. ft.

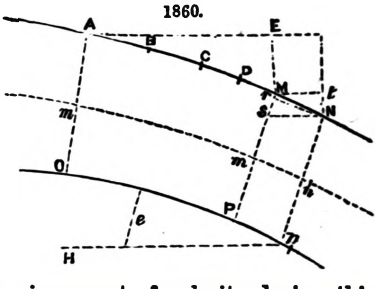
In homogenous earth, so long as the depth of excavation does not exceed $6\frac{1}{2}$ ft., and the upper width $16\frac{1}{2}$ ft., the expense of digging will be proportional to the volume of excavation, and the figure of least section will therefore be the most economical.

21. As for those canals where there is no fear of caving in, such as those excavated in rock, or protected with masonry, which are more particularly termed Aqueducts, as well as those in wood and mill courses, they most always have a rectangular form. Still, as we have seen, the regular demi-hexagon of the same section will conduct more water; but simplicity, facility, and economy of construction have prevailed. We must remember that the dimensions of the rectangle should have a width nearly double the depth of the fluid mass it is destined to carry, and consequently it should be $\sqrt{\frac{2 Q}{v}}$.

22. *Permanent Motion.*—We have seen (10) that permanent motion differs essentially from uniform in this, that the mean velocity in each section, remaining constant, is not the same as in the adjacent sections; consequently, the sections of water are no longer equal to each other, their depth is not the same, the surface of the fluid is not parallel to that of the bed of the stream, and its inclination varies from one point to another. We have examples of such motion in canals too short for the velocity to acquire a uniformity, at the head and foot of long canals, and in those whose bottom is horizontal.

23. Let there be a current endowed with permanent motion, and let us regard that part of it comprised between A and M, Fig. 1860. Through these two points of the surface, and through N infinitely near to M, imagine transverse sections A O M P, and N $p$, made perpendicular to the axis of the current. From the points A and M we draw the horizontal lines A E and M $t$; E M will be the fall of the surface from A to M, which we designate by $p'$; $t$ N, or the elementary increment of the slope, will be $d p'$ or M N sin. $i$, $i$ being always the angle $t$ M N of inclination of the surface to the horizon. Let us consider upon the section A O, taken up stream for the point of departure, the particle having the mean velocity of the section, whatever else may be its position, and let $m m'$ be the path which it describes as far as M P. Call $z$ the length of this path, $t$ the time employed in traversing it, and $v$ the velocity of the particle on arriving at $m$. We have then $m' n' = d z$; $d t$ will be the time in passing $d z$, and $d v$ the increment of velocity during this passage (which will be $- d v$ when motion is retarded).

1860.




The forces which act upon the particle $m$ while traversing $m m' n'$ are: 1st, on one side, gravity, which tends to accelerate its motion, and whose whole action, according to what we have said in (3), is $g$ sin. $i$; 2nd, on the other side, the resistance of the bed, which tends to retard its motion, and whose expression is (7) $a' \frac{c}{s} (v^2 + b v)$.

These two forces acting opposite to each other, their resultant, or the effective accelerating force, will be equal to their difference. But in all variable motion, the accelerating force is also expressed by the increment of the velocity, divided by that of the time, or by $\frac{d v}{d t}$; we have then

$$\frac{d v}{d t} = g \text{ sin. } i - a' \frac{c}{s} (v^2 + b v).$$

Multiplying all the terms by $dz$ (remarking that $\frac{dz}{dt} = v$, the space, divided by the time, equalling the velocity; remarking, further, that $dz \sin. i = dp'$, since for $dz$ or $m'n'$ we may take M N, which will not differ from it save in extreme cases, but by an infinitely small quantity of the second order, and that M N sin. $i = t$ N $= p'$), we have $v\,dv = g\,dp' - a'\frac{c}{s}(v^2 + bv)\,dz$.

Such is the equation established by Poncelet.

Integrating, determining the constant for the section A, when $p' = 0$, $z = 0$, and $v = v_0$, we have

$$\frac{v^2}{2} - \frac{v_0^2}{2} = g\,p' - \int a'\frac{c}{s}(v^2 + bv)\,dz.$$

But (8) $v = \frac{Q}{s}$; and if we designate by $s_n$ the area of the section at the final point M, and by $s_0$ that at the initial point A, which let us divide by $g$, and remembering that $\frac{a'}{g} = a = 0{\cdot}000024265$ (12), and that $b = 0{\cdot}000111415$, we have finally

$$p' = \frac{Q^2}{2g}\left(\frac{1}{s_n^2} - \frac{1}{s_0^2}\right) + \int\left(0{\cdot}0001114155\,\frac{c\,Q^2}{s^3} + 0{\cdot}000024265\,\frac{c\,Q}{s^2}\right)dz;$$

a formula which gives directly the slope of the surface from A to M.

In the application, the quantity under the sign $\int$ may be integrated by approximation. For this purpose, divide the arc A M or $z$ into portions, A B, B C, C D, and so on, whose lengths are such that the divisions of the arc may be taken, without sensible error, for right lines. Designate these lengths by $z'_1, z'_2, z'_3 \ldots z'_n$, and the areas of the sections at A, B, C . . . . M, by $s_0, s_1, s_2, s_3 \ldots s_n$, and by $c_0, c_1, c_2 \ldots c_n$, their respective wetted perimeters. We measure or take immediately these lengths, sections and perimeters upon the given stream, and all will be known in the integral, which will become

$$0{\cdot}0001114155\left(\frac{z'_1 c_1}{s_1^2} + \frac{z'_2 c_2}{s_2^2} + \ldots \frac{z'_n c_n}{s^n}\right)Q^2 + 0{\cdot}000024265\left(\frac{z'_1 c_1}{s_1^2} + \frac{z'_2 c_2}{s_2^2} + \ldots \frac{z'_n c_n}{s_n}\right)Q.$$

Let us represent by M the multiplicator of $Q^2$, and by N that of Q; let us make also $\frac{1}{2g}\left(\frac{1}{s_n^2} - \frac{1}{s_0^2}\right) = D$, the equation will then be $p' = (D + M)\,Q^2 + N\,Q$.

24. From this we deduce $Q = -\frac{N}{2(D+M)} + \sqrt{\frac{p'}{D+M} + \left(\frac{N}{2(D+M)}\right)^2}$.

In our article on Rivers we shall have occasion to apply this formula, with its details, to streams whose form and delivery were otherwise known, and we shall see that its deductions are not far from the truth.

In canals where the slope of the bed and the profiles are constant, the calculations are much simplified; the depth of water at any one station will be sufficient to know its section and wetted perimeter; moreover, the depths, with the inclination of the bed, will give that of the surface.

As an example, let us determine the volume of water which a rectangular mill-course, 8·202 ft. wide, with a horizontal bed, will conduct to a mill. At four points, distant 328·1 ft. apart, we

| No. | $z'$ | $h$ | $c$ | $s$ | $\frac{z'c}{s^2}$ | $\frac{z'c}{s^3}$ |
|---|---|---|---|---|---|---|
| | feet. | feet. | feet. | sq. ft. | | |
| 0 | 0 | 5·052 | 18·306 | 41·44 | 0 | 0 |
| 1 | 328·09 | 4·901 | 18·004 | 40·20 | 3·655 | ·0909 |
| 2 | 328·09 | 4·845 | 17·892 | 39·74 | 3·717 | ·0935 |
| 3 | 328·09 | 4·573 | 17·348 | 37·51 | 4·045 | ·1078 |
| | P | ·479 | | | 11·417 | ·2922 |

take four depths, noted in column $h$ of Table. Since the canal is rectangular, and $l = 8{\cdot}202$ ft., then $s = 8{\cdot}202\,h$ ft., and $c = 8{\cdot}202 + 2h$ ft. We calculate these values for the different stations, and then, through these, those of $\frac{z'c}{s^2}$ and $\frac{z'c}{s^3}$. All are in the above Table.

The canal being horizontal, $p' = 5{\cdot}052 - 4{\cdot}573 = {\cdot}479$ ft. We have

$$D = \frac{1}{64{\cdot}364}\left(\frac{1}{37{\cdot}51} - \frac{1}{41{\cdot}44^2}\right) = \ldots\ldots\ldots\ldots\ldots\ldots\ 0{\cdot}000001995$$

$$M = \text{sum of } \frac{z'c}{s^3} \times 0{\cdot}0001114155 = \ldots\ldots\ldots\ldots\ldots\ldots\ 0{\cdot}00003255$$

$$N = \text{sum of } \frac{z'c}{s^2} \times 0{\cdot}000024265 = \ldots\ldots\ldots\ldots\ldots\ldots\ 0{\cdot}0002770$$

$$\frac{N}{2(D+M)} = 4{\cdot}0092, \quad \frac{p'}{D+M} = 13866, \quad \left(\frac{N}{2(D+M)}\right)^2 = 16{\cdot}0742 \text{ ft.}$$

So that $Q = -4{\cdot}0092 + \sqrt{13866 + 16{\cdot}0472} = 113{\cdot}81$ cub. ft.

With the formula for uniform motion in taking a mean height between the extreme heights, and for a slope per foot, ·479 divided by 984·27 ft., the sum of the $x'$, we have

$$Q = -4{\cdot}299 + \sqrt{15072 + 18{\cdot}478} = 118{\cdot}54 \text{ cub. ft.}$$

25. The equation (23) which gives the slope of the surface of the current knowing some of the sections, will further, by the taking of one depth only, enable us to trace in its progress the curve described by a fluid point of the surface of a water-course in a canal, whose slope, profile and discharge are otherwise known.

For the place, when the depth of water is given by the aid of the profile, it will be easy to establish its section and wetted perimeter; let us designate them by $s_0$ and $c_0$. Take a second station, at a distance $z'$ from the first, so small, that in this distance there shall be but little variation in $s_0$ and $c_0$, and so that they may be regarded as constant in the expression of the resistance of the bed, and we have $p' = \frac{Q^2}{2g}\left(\frac{1}{s_1^2} - \frac{1}{s_0^2}\right) + a c_0 \left(\frac{Q^2}{s_0^3} - \frac{Q}{s_0^2}\right) z'$.

We may neglect the first part of the second member at the first trial, which amounts to supposing a uniform motion throughout the whole length $z'$, and we shall have the first approximate value of $p'$. This will enable us, knowing the slope of the bed, to assign very nearly the depth of the stream at the second station, and consequently gives us $s_1$. All will then be known in the above equation, and we have a second and more approximate value of $p'$ than the first. If it is thought best, we are able from this to calculate a third, which shall be still more exact. In the same manner, we may determine the depth at the third and fourth stations, and so arrive at all the ordinates of the curve required to be constructed.

26. But this method involves much uncertainty, and many suppositions, and often leaves us much embarrassed. We can avoid, in part, these inconveniences, and go directly to the solution of the problem, by introducing the slope of the bed in the problem, according to the method of Bélanger.

For this purpose let us take in hand the first differential equation of (23); and we remark that the angle $i$, or $t\,\mathrm{M}\,\mathrm{N}$, or $\mathrm{M}\,\mathrm{N}\,s$, Fig. 1860, is composed of two other angles: first, $\mathrm{M}\,\mathrm{N}\,r$, which measures the inclination of the surface upon $\mathrm{N}\,r$, parallel to the bottom of the bed $\mathrm{P}\,p$; designate this by $j$: second, the angle $r\,\mathrm{N}\,s$, which this bottom makes with the horizon, and which we have already called $e$; so that $i = j + e$, and consequently, sin. $i$ = sin. $j$ cos. $e$ + sin. $e$ cos. $j$. But sin. $e = p$ (1), cos. $e = \sqrt{1 - p^2}$, and cos. $j = 1$, considering the smallness of the angle $j$; thus sin. $i$ = sin. $j\sqrt{1 - p^2} + p$, and the equation becomes

$$\frac{dv}{dt} = g \sin. j \sqrt{1 - p^2} + gp - a' \frac{c}{s}(v^2 + b\,v). \qquad [\mathrm{A}]$$

The term $\frac{dv}{dt}$ may take a finite form, which will depend upon the figure of the bed. When the canal is of small extent, we usually consider the slope as uniform, with a mean width $l$. From this supposition results $s = l\,h$ and $c = l + 2\,h$; so that $v = \frac{Q}{s} = \frac{Q}{l\,h}$, and $dv = -\frac{Q\,l\,dh}{l^2 h^2}$; moreover (23), $v = \frac{dz}{dt}$ or $dt = \frac{dz}{v} = \frac{l\,h\,dz}{Q}$; then $\frac{dv}{dt} = \frac{Q^2\,l\,dh}{l^3 h^3\,dz} = \frac{Q^2\,l}{l^3 h^3}$ sin. $j$, since $\frac{dh}{dz} = \frac{\mathrm{M}\,r}{\mathrm{M}\,\mathrm{N}} = -$ tan. $i$ or $-$ sin. $j$.

Substituting this value in the equation [A], neglecting $p^2$, which will always be small compared to 1, substituting for $g$, $a'$ and $b$ their numerical values (12), and evolving sin. $j$, we have

$$\sin. j = \frac{\mathrm{P}\,l^3 h^3 - \{\,0{\cdot}0001114155\,(l + 2\,h)\,Q^2 + 0{\cdot}0000242651\,(l + 2\,h)\,l\,h\,Q\,\}}{{\cdot}031073\,l\,Q^2 - l^3 h^3}.$$

We have taken for the curve of a fluid thread of the surface of the stream, a polygon, each of whose sides has a finite length $\mathrm{M}\,\mathrm{N} = z'$, and whose inclination relative to the bed is $j$: the difference $\mathrm{M}\,r$ between the depths of the two extremities of a side will be its slope compared to this bottom; designating it by $p''$, we have sin. $j = -\frac{p''}{z'}$, and consequently,

$$p'' = \frac{p\,l^3 h^3 - \{\,0{\cdot}000111415\,(l + 2\,h)\,Q^2 + {\cdot}0000242651\,(l + 2\,h)\,l\,h\,Q\,\}\,z'}{l^3 h^3 - {\cdot}031073\,l\,Q^2}.$$

The series of values of $p''$ will enable us to trace the polygon, or required curve.

Instead of comparing the slopes to the bed, we might compare them with the horizon, and thus have their value $p'$, in observing that $p' = p'' + p$.

*Inlets.*—Canals, with the exception of those for navigation, at their points of departure receive their water from reservoirs or retaining basins placed at their heads, and which most frequently are portions of the river whose level has been raised for this purpose by dams.

The head of the canal, at the point for receiving water, is either entirely open, or furnished with gates. Let us examine these two cases.

27. *Canals of Open Entrance.*—Water, on its entrance into an open canal, forms a fall, its level being lowered for a certain distance: then it is elevated a little by slight undulations, beyond which the surface takes and maintains a form very nearly plane and parallel with the bed, its slope and profile being always considered as constant. The velocity is accelerated from the top to the foot of the fall; it then diminishes during the elevation of its surface, and, soon after, its motion continues in a manner sensibly uniform. Dubuat, who has made a particular study of the circumstances of motion at the entrance of canals, and throughout their course, has found such an order of things established, that when the motion has become regular and uniform, the velocity of the surface is very nearly that due to the entire height of the fall, and that the *head due to the mean*

*velocity is equal to the difference between the height of the reservoir and that of the uniform section.* So that if H represent the height of water in the reservoir above the sill of entry into the canal, $h$ the height of the uniform section, that is to say, the constant depth of the current after it has attained a uniform motion, and $v$ the velocity of this motion, we have $H - h = 0{\cdot}015536\, v^2$; or rather, $0{\cdot}015536 \frac{v^2}{m^2}$, $m$ being the coefficient of contraction which the fluid mass experiences at its entrance into the canal, a contraction which occasions a greater fall.

Dubuat, from several experiments made with wooden canals (9), with heights of reservoir H from ·394 ft. to 2·887 ft., has found that $m$ varies from 0·73 to 0·91; but he remarks that, in great canals, where the height due to the velocity is small compared to the depth, the contraction will be less, and he thinks there would be no sensible error in taking $m = 0{\cdot}97$. Eytelwein assumes 0·95 for large canals, and 0·86 for the narrow, such as is adopted for most mill-courses. He, as well as Dubuat, supposes, for these coefficients, that the bottom of the canal is at the same level with the bottom of the reservoir, and that it is but a prolongation of it. If this were not the case, there would be a contraction at the bottom, and the value of $m$ would be a very little smaller.

28. The fall which takes place at the entrance of a canal, by diminishing the depth $h$, lessens the discharge Q, of which this depth is an element. So that, in order that the canal should receive all the water which it can afterwards convey, we must prevent the fall.

Theoretically, to accomplish this end we must enlarge the upper part of the canal for a length somewhat beyond $·015536 \frac{v^2}{p}$ ft., so that the mean widths of the new profile should increase as they approach the reservoir, with an inverse ratio to the velocity of the stream at each of these widths, beginning with 0, its value in the reservoir, till, by the uniform acceleration of its descent, it reaches $v$ ft. at the foot of the enlarged part. According to this law, the width at the reservoir should be infinite, since the velocity is zero. Such a case would be impracticable, and any approach to it would involve much labour and expense.

Consequently, the engineer who, without involving himself in unnecessary expense, desires to obtain for the canal all the water that can reasonably be expected, will be content to widen the approach, and in doing this must be governed by local circumstances. For instance, if the head is to be laid in masonry, he will give to the approach the form of the contracted vein; that is to say, taking the width of the canal as a unit, we shall have for length of the enlarged part 0·7, and 1·4 for width at the mouth, as comprising the full sweep to be given to the angles. But it is not worth while to exaggerate the advantages from these widenings, as the discharge by them will hardly be increased by more than some hundredths.

29. Dubuat also concludes, from his observations, *that the velocity and section are uniformly established at a certain distance from the reservoir, just as if uniformity commenced at the origin of the canal.* In this case we may suppose the fall to be made suddenly on its entrance to the canal, and thence the fluid surface maintains a uniform slope. Its value is obtained (1 and 11) by dividing the difference of level of the two points by their distance apart; one may be taken at the origin of the canal, and according to our supposition its level will be less than that of the reservoir, by a quantity equal to the height of the fall $H - h$. Consequently, if D is the difference of level between the reservoir and any point of the surface at the distance L from the reservoir, but where the motion has acquired its uniformity, $p$ being always the effective slope, we have

$$p = \frac{D - (H - h)}{L} = \frac{D - 0{\cdot}015536\, v^2}{L}.$$

30. With these given quantities we can resolve the various questions pertaining to a canal from a reservoir, supposing always that the motion becomes uniform, which will not be the case unless the canal has a certain length, or should it have no inclination, or approach 90°, and so on.

Let us resume the equation, $H - h = 0{\cdot}015536 \frac{v^2}{m^2}$, and in place of $v$ substitute its value, given in (13), and we have $H - h = \frac{0{\cdot}015536}{m^2} \left( \sqrt{8975{\cdot}414 \frac{ps}{c}} - {\cdot}108895 \right)^2$.

Moreover, we have $Q = s \left( \sqrt{8975{\cdot}414 \frac{ps}{c}} - {\cdot}108895 \right)$.

By means of these two equations, in giving to $s$ and $c$ their expression, as functions of the dimensions of the canal, and substituting the preceding value of $p$, when $p$ is not directly given we can determine either the discharge, or the slope, or one of the dimensions; the other quantities being known. We give an example.

Suppose we purchase the site where it is intended to locate the entrance to the canal, with the condition that it shall be rectangular in form, open to the height of the dam, with a width of 13·124 ft., and whose sill is to be 6·562 ft. below the ordinary low-water line. We wish to conduct this water to a mill distant 869·438 ft., so that the surface of the stream, on its arrival there, shall not be over 1·4436 ft. below the low-water mark of the reservoir above. What will be the quantity of water conducted to the mill?

The cutting being made in the dam, the rectangular canal 13·124 ft. by 6·562 ft. deep is fitted in; the clause of the grant forbids any attempt to enlarge the approach; and every alteration within the appointed limits would diminish the discharge.

Since the canal is rectangular, and 13·124 ft. wide, we have $s = 13{\cdot}124\, h$ ft., and $c = 13{\cdot}124$ ft. $+ 2h$; moreover, $p = \frac{1{\cdot}4436 - (H - h)}{869{\cdot}4384} = \frac{h - 5{\cdot}1184}{869{\cdot}4384}$ ft., H being 6·562 ft. Although the canal is large,

so that the coefficient of contraction would probably be above 0·95, yet, to be prudent, we will take a mean between those indicated by Eytelwein, and call it $m = 0{\cdot}905$. With these values the first of the two equations above will be

$$6{\cdot}562 - h = \frac{0{\cdot}015536}{{\cdot}905^2}\left(\sqrt{8975{\cdot}414\,\frac{13{\cdot}124\,h\,(h - 5{\cdot}1184)}{869{\cdot}4384\,(13{\cdot}124 + 2h)}} - {\cdot}108895\right)^2.$$

Reducing $6{\cdot}562 - h = {\cdot}018969\left(\sqrt{135{\cdot}47\,h\,\frac{(h - 5{\cdot}1184)}{(13{\cdot}124 + 2h)}} - {\cdot}108895\right)^2$ gives us the value of $h$.

To obtain it, put successively for this unknown quantity in the second member, several numbers; first, 6·234 gives $h = 5{\cdot}889$ ft.; which in its turn gives 6·114. In this manner we obtain successively 5·968, 6·053, 6·001, 6·040, 6·014, 6·034, 6·020, 6·027, 6·0237 ft. Thus the true value of $h$ falls between these two last numbers; let us take the smallest, $h = 6{\cdot}0237$ ft. Then

$$p = \frac{6{\cdot}0237 - 5{\cdot}1184}{869{\cdot}4384} = 0{\cdot}001041 \text{ ft.}$$

All the quantities required to ascertain the discharge being known, we introduce them into the second equation, and so obtain $Q = 417{\cdot}795$ cub. ft. Such is the volume of water per second which the canal will lead to the mill.

When the velocity of the current is required to be 3·28 ft. or more, we substitute the expression for velocity given in (15), and the two equations to be used will be

$$H - h = \frac{139{\cdot}44}{m^2} \cdot \frac{ps}{c} \text{ and } Q = 94{\cdot}738\,s\sqrt{\frac{ps}{c}};$$

or, supposing a mean width $l$, and taking always $m = {\cdot}905$,

$$H - h = 170\,\frac{plh}{l + 2h} \text{ and } Q = 94{\cdot}738\,lh\sqrt{\frac{plh}{l + 2h}}.$$

The slope $p$ will be given either directly, or by the expression $p = \dfrac{D - (H - h)}{L}$.

In the above example, the values of H, $l$ and $p$, put in the first of these equations, which is of the second degree, will give readily $h = 6{\cdot}027$ ft.; also, $p = {\cdot}001045$ and $Q = 418{\cdot}86$ cub. ft.; results nearly identical with the preceding.

31. Among the questions relating to the admission of water in canals, there is one of too much interest to millwrights for us to pass it by without a notice in this work.

The force of a current to move machinery depends not only upon the quantity of water which it conveys, but also upon the height from which it falls; so that this force will be measured by the product of the quantity with the height of the fall of water. The greater the slope given to the canal, the greater will be the amount of water brought, and this is one of the factors of the product; but, at the same time, the fall (the other factor) is diminished, and it will be found that the product having been at first augmented with the slope, will after that be diminished, and then continue to decrease. There is then a *maximum* of power, which it is essential to determine and put in use. Without employing analytical formulæ, this determination can be arrived at in a simple manner, as will be seen in the following example.

Let us resume that given in the last number, and let us suppose the height of fall there to be 14·764 ft. The water taken by the canal has arrived at the mill with a loss of level of 1·447 ft.; consequently, the effective fall will only be 13·317 ft. In multiplying this by the quantity of water brought down, 418·86 cub. ft., we have for the product 5577·9 cub. ft.; the corresponding slope was 0·001045. Let us increase this slope successively to 0·0015, ·002, ·0025, and ·003; the respective products of the quantity by the fall will be 1859·42, 1931·12, 1939·94, and 1907·45 cub. ft. The slope of ·003 has already occasioned a diminution; in trying that of ·0026, the product will be 1938·18 cub. ft.; whence we conclude that the *maximum* of effect lies between the slopes of 0·0025 and ·0026. Finally, as the variations of the product are very small between 0·002 and 0·003, we adopt, between these limits, those best suited to the locality and nature of the machinery used; there may be some for which a great fall will be preferred.

We will remark that the given solutions of all the problems in question can be regarded only as simple approximations; for in order that they should be exact, the bases on which they rest, that is to say, the conclusions which Dubuat has drawn from experiments, should be explicitly confirmed by observations made upon great canals; and it would, moreover, be necessary to be quite sure that the water, before it reaches the extremity of the canal, has attained a uniform motion, and we have but limited means of coming to a positive assurance.

If water which is in the reservoir of a river to which a canal has been adapted, should arrive there directly, with an acquired velocity, the height of fall which takes place at the entrance will be less than that indicated (27) by a quantity equal to the height due to this velocity.

*Canals with Gates.*—When a canal receives its water through openings of a system of gates, established at its head, which is generally the case with mill-courses, either the upper edge of the orifice will be completely and permanently covered by the water already passed into the canal, or it will not.

32. If the head above the centre of the orifice is great, so as to exceed two or three times the height of the orifice, its upper edge will not be covered by the water below, and the discharge will be the same as if there had been no canal. Experiments with orifices in thin sides and furnished with additional canals, leave no doubt upon this subject; they justify an assertion, long since made by Bossut, the exactness of which has been questioned.

Bossut fitted to an orifice ·0886 ft. high and ·4429 ft. wide, made at the bottom of a reservoir, a horizontal canal of the same width, and 111·55 ft. in length; he produced in it currents under

heads of 12·468 ft., 7·802 ft., and 3·937 ft., and he received at the extremity of the canal the same quantity of water that issued from the orifice when the canal was taken away.

The cause of this equality is apparent. When the water is urged by a great head, and consequently issues with great velocity, the contraction it experiences on all sides renders the section smaller immediately beyond the interior plane of the orifice, so that, on issuing, it touches neither the sides nor the bottom of the canal; it acts as if it were projected in air, and the discharge continues the same that it would if this were really the case. Beyond the contracted section the vein dilates, it is true; it joins the sides of the canal; it meets with resistance, and runs less swift; but then it is too far from the orifice to react against what issues from it, so as to reduce its discharge. This will always be given by the formula $m\,l'\,h'\,\sqrt{2\,g\,H}$, $l'$ and $h'$ being the width and depth of the orifice; $m$ will have the same value as for orifices in thin partitions.

Generally, we take 0·70 for the coefficient of ordinary gates of flumes. See Poncelet and Lesbros' experiments.

Without adopting another coefficient for each particular case, the volume of water which enters a canal furnished with large gates, and under a great head, may be had approximately by the formula $0{\cdot}70\,l'\,h'\,\sqrt{2\,g\,H}$.

33. When the water, impelled beyond the gates by a great head, falls into the canal, it meets a resistance which diminishes gradually its first velocity, and so increases the section of its current. If the width of the canal is constant and equal to the opening of the gate, it will be the depth which receives the gradual increase; so that the surface of the fluid below the orifice, or rather below the point of greatest contraction, up to that where the increase of depth ceases, will present a counter-slope. Frequently masses of water will be detached from the summit, and will, rolling back, return towards the orifice; usually they will be retained, being as it were repelled by the velocity of the stream; though sometimes they will return even to the gate, and re-cover the orifice, though but for a moment. Even in this case the discharge will be the same as if there were no canal, and it will be calculated by the formula of the preceding number.

34. These phenomena do not occur when the head is small. Water, on issuing from the gates, is in contact with the sides of the canal; it experiences a retarding force, which is communicated to the fluid at the instant of its passage through the orifice; the discharge, and therefore its coefficient, is lessened; but we have no further guide for its determination. There may be some cases where, with a very small head, the gate is without sensible influence; thus Eytelwein has found the same discharge, whether the gate was wholly raised, or slightly dipped on the down-stream side.

But in case it is immersed any considerable depth, and the fluid vein at its issue is entirely covered over with still water, the height due to the velocity of issue will be the difference between the elevation (above any given point) of the surface above the gate and of that below the gate. For the elevation below the gate we take the height or depth of water in the canal, when its motion has become regular; as that immediately at the gate would be found too small. Consequently, if $h$ is the height in the canal, H′ the height up stream above the sill of the inlet, the discharge of the orifice of the gate, and consequently that of the canal, will be expressed by $m\,l'\,h'\,\sqrt{2\,g\,(H'-h)}$. But the discharge of the canal, the motion having become uniform, is also (14) $s\left(\sqrt{8975{\cdot}414\,\frac{p\,s}{c}}-{\cdot}108895\right)$.

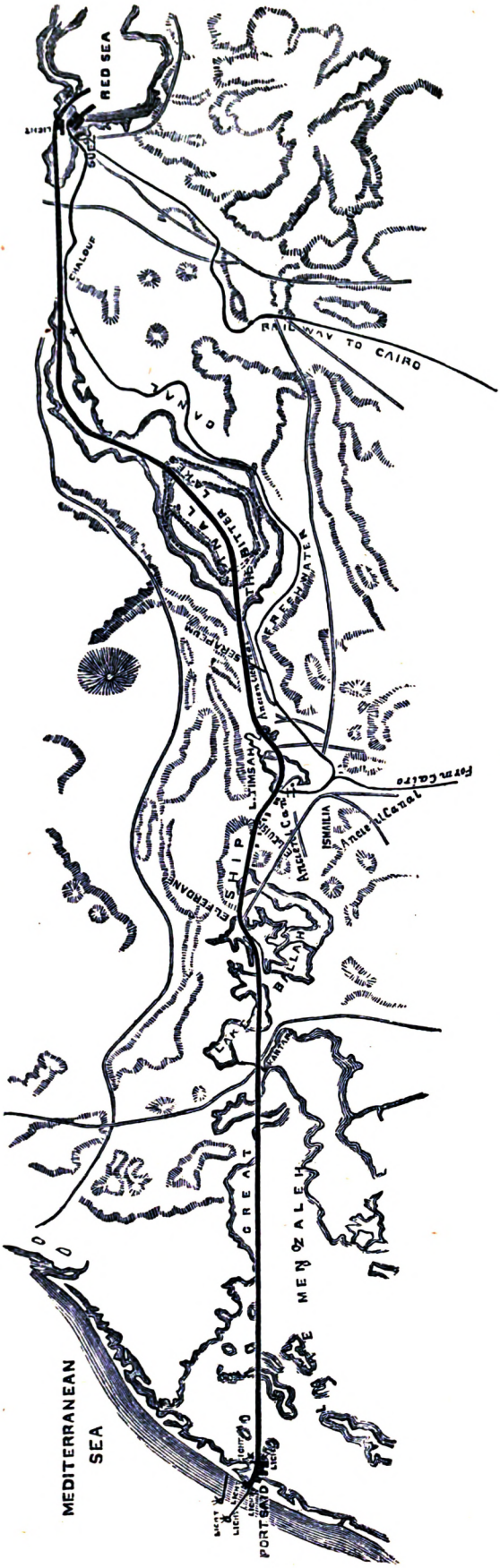
We have then $m\,l'\,h'\,\sqrt{2\,g\,(H'-h)}=s\left(\sqrt{8975{\cdot}414\,\frac{p\,s}{c}}-{\cdot}108895\right)$, an equation which enables us to solve the various questions relative to canals furnished with gates at their heads.

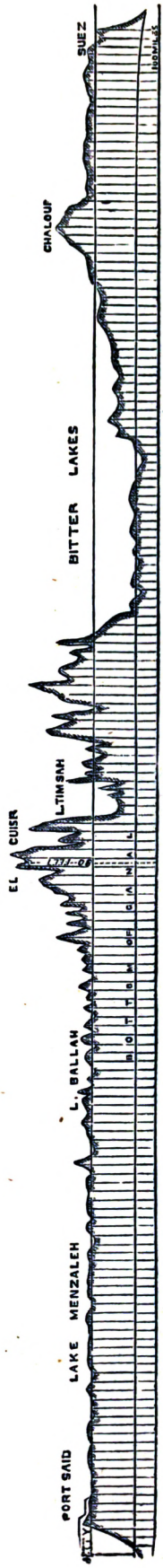
Suppose, for instance, we would determine the quantity $h'$; we must raise the gate, at the entrance of a long rectangular canal of 4·265 ft. width and ·001 slope, in order that the water may have a depth of 2·625 ft.; the width of the gate is 3·609 ft., and the height of the reservoir 3·937 ft. We take $m = 0{\cdot}70$ (32). We have then $l' = 3{\cdot}069$ ft.; $H' = 3{\cdot}937$; $h = 2{\cdot}625$; $l = 4{\cdot}265$; $p = 0{\cdot}001$; $s = 4{\cdot}265 \times 2{\cdot}625 = 11{\cdot}195$ sq. ft.; $c = 4{\cdot}265 + 2 \times 2{\cdot}625 = 9{\cdot}515$ ft. These numerical quantities, substituted in the equation above, give us $23{\cdot}209\,h' = 35{\cdot}180$; whence $h' = 1{\cdot}514$ ft.

*The Suez Canal.*—The plans and sections of the Suez Canal given in Figs. 1861 to 1867, are, with some trifling additions, the same as those compiled by Sir W. T. Denison from 'Compagnie Universelle du Canal Maritime de Suez: Carte générale de l'Isthme, etc., 1866;' and the plans of Port Saïd and of the Port of Suez, from 'Percement de l'Isthme de Suez: Actes constitutifs de la Compagnie Universelle du Canal Maritime de Suez, avec cartes et plans;' documents publiés par F. de Lesseps, the engineer of this great work. Our additions are taken from 'Histoire de l'Isthme de Suez,' par Olivier Ritt, 1869. Sir W. T. Denison's paper "On the Suez Canal" was read in the Institution of Civil Engineers, 16th April, 1867, and afterwards published in pamphlet form, edited by James Forrest, the secretary of the Institution. The thick black line in the plan, Fig. 1861, indicates the course, and Fig. 1862 is a vertical longitudinal section, of the canal; the horizontal lines in Figs. 1861, 1862, are to a scale of ·09 in. to a mile, and the ordinates, Fig. 1862, ·01 in. to a foot. Fig. 1864 is a cross-section at Port Saïd, and Fig. 1863 a cross or lateral of the canal at Suez; the scale of these sections is ·008 in. to a foot. Fig. 1865 is a plan of Port Saïd and the harbour on the Mediterranean; Fig. 1866 is a plan of the port of Suez, on the Red Sea: the plans of these places are given to a scale of 1000 yds. to an inch. The motions and actions of the water of the canal may be calculated, by the rules just established, from the levels, inclinations, and dimensions registered on Figs. 1867, 1863, and 1864.

Col. Denison, in his notes, as the work was being completed, observed:—The scheme of the Suez Canal may be said to comprise two distinct undertakings. The first, and principal, is the con-

1861.

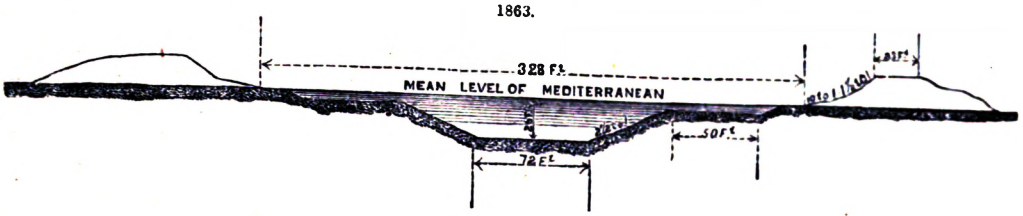

RED SEA
SUEZ
CHALOUF
RAILWAY TO CAIRO
CANAL
BITTER LAKES
FRESHWATER
SERAPEUM
L. TIMSAH
Ancient Canal
Form Cairo
ISMAILIA
Ancient Canal
EL FERDANE
SHIP
BALLAH
LAKE
GREAT
MENZALEH
MEDITERRANEAN SEA
PORT SAID


SUEZ
CHALOUF
BITTER LAKES
L. TIMSAH
EL CUISR
BOTTOM OF CANAL
L. BALLAH
LAKE MENZALEH
PORT SAID

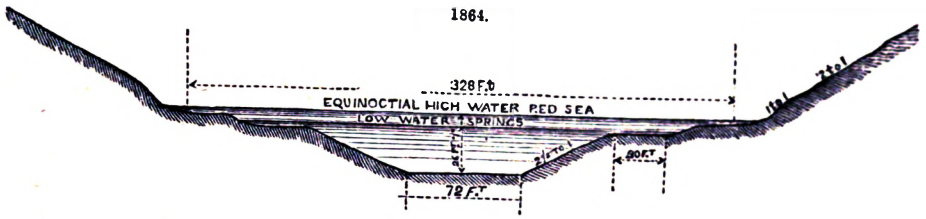
1862.

struction and maintenance of a broad and deep salt-water channel on one level between Port Saïd on the Mediterranean, and Suez on the Red Sea. The second, preliminary in point of time, and indeed essential to the construction, as well as to the beneficial use of the canal, is the maintenance of a supply of fresh water sufficient for the wants of the population congregated along the line of canal, and specially at its two extremities.

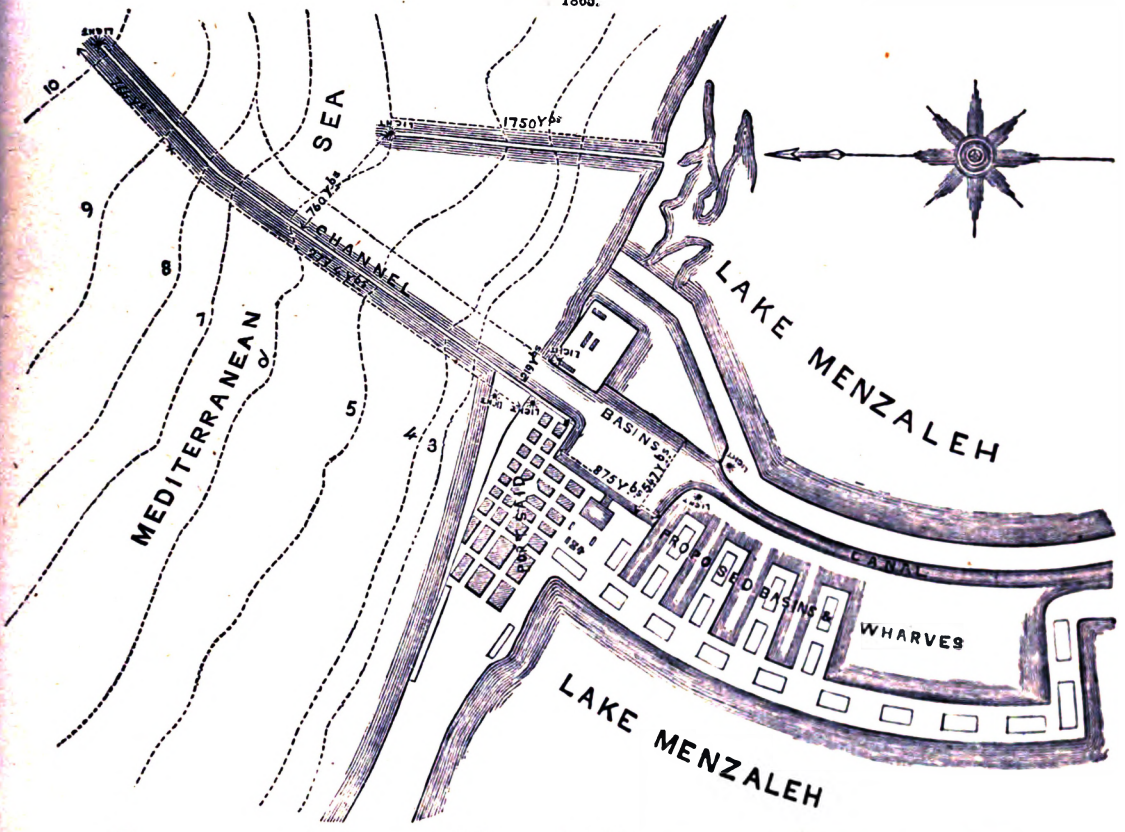
1863.




1864.




1865.




The arrangements for the second of these undertakings have been completed. A canal, commencing at a place called Zagazig, to which water is brought from the Nile by one of the many branches from the main stream, has been carried to Suez, passing within about a mile or two of Ismaïlia, the central point of the main canal, and the head-quarters of the establishment of the Company. It is navigable for the whole distance, the fall from Zagazig to Suez being overcome by locks. From the point where the canal turns southward to Suez, a branch is carried first to Ismaïlia, where it provides a supply for the inhabitants, and for some hydraulic machinery, by which water is forced into a double line of 9-in. pipes, through which fresh water is carried along the side of the canal, supplying the various establishments along the line of about 50 miles in length, and a population at Port Saïd already numbering upwards of 10,000; and secondly, for a distance

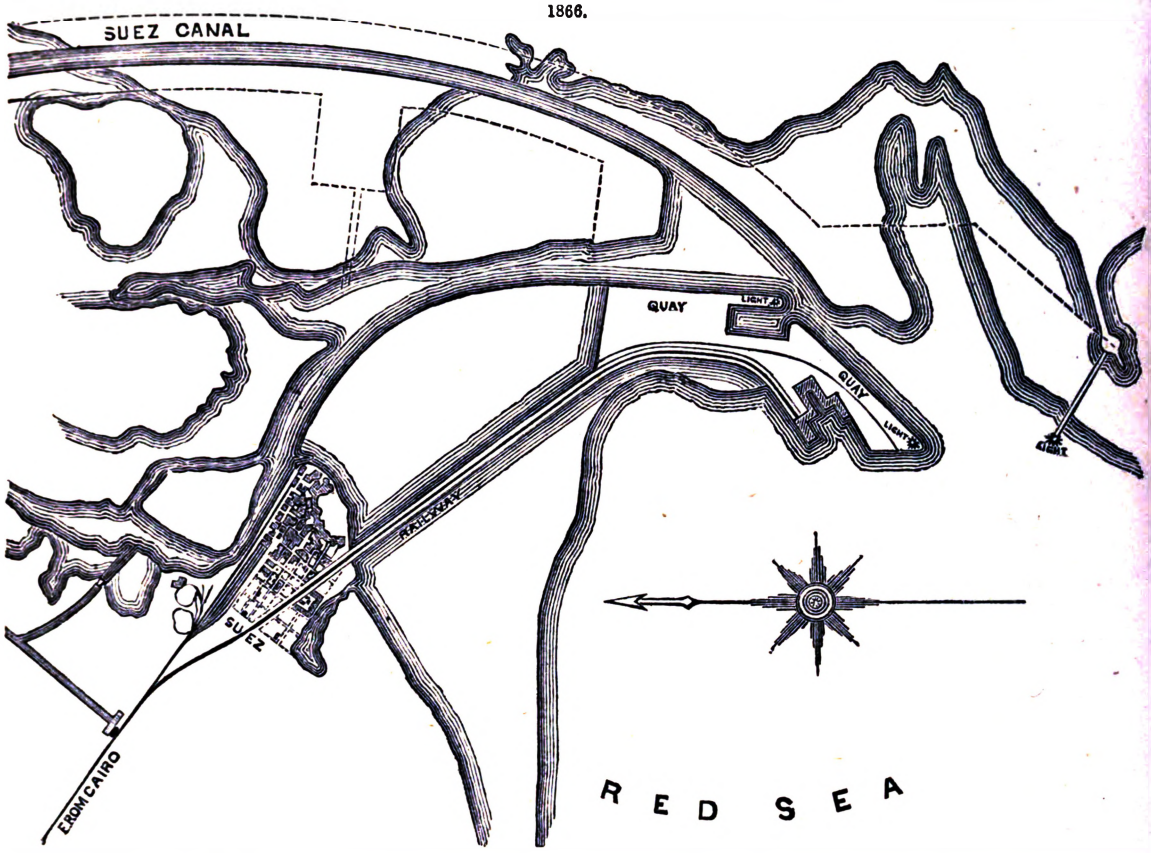
of about a mile to the east of Ismaïlia, within which distance it is made to drop by two detached locks to the level of the Mediterranean. At the Suez extremity the fresh-water canal terminates in a lock, by which vessels drop into the creek which brings goods and passengers from the anchorage to the town.

In the immediate vicinity of the anchorage a dry dock, capable of taking in the largest steamer, is constructed.

The salt-water canal commences to the south-east of outer port, the ground being dredged out to the necessary depth, and to a width sufficient to give ample space for the exit and entrance of vessels. The canal sweeps away in a curved line towards the north, passing to the eastward of the fresh-water canal through the lowest portion of the land, which is, in point of fact, very little above the level of the Red Sea. Figs. 1861, 1862.

At a distance of 11¼ miles from the sea, the line crosses a spur from some nills to the westward, at a place called Chalouf: the cutting here consisted partly of a bed of hard conglomerate, 8 or 10 ft. in thickness, below which were strata of sand and clay. The surface of the soil at this cutting was about 12 ft. above the salt-water level, so that the total depth of excavation is 40 ft. The slope of the side was 2 to 1, and there was left a bench of about 12 ft. in width, 3 ft. above the surface of the water; while another bench, 12 ft. below the water, and 9 ft. wide, formed a base for the stonework employed to face the upper part of the slopes. The stone was procured in part from the excavation itself, and in part from quarries on the west shore of the Red Sea, a few miles south of Suez. The work here was carried on with a good deal of method. Inclined planes were cut in each bank, up which the wagons filled with spoil were hauled by steam-engines, and then drawn to spoil-banks at convenient distances. Pumps discharged the drainage water into a portion of an old salt-water canal, said to have been excavated by one of the Pharaohs.

1866.




Soon after leaving this cutting the canal had to pass through the Bitter Lakes, the surface of the water, or soil, in which is nearly on a level with the Red Sea. Here the cutting did not exceed the ordinary section of the canal.

The distance between Suez and Ismaïlia is about 50 miles.

A little east of Ismaïlia the branch from the fresh-water canal comes to an end, and passenger boats drop by two single detached locks to the level of the Mediterranean, into a salt-water canal about the same size as the other. For some distance this was only a branch, but at about 2 miles from Ismaïlia the branch enters the line of the main canal, which turns sharp to the left or northwards, and passes through a heavy sand-bank from 40 ft. to 60 ft. above the level of the surface water in the canal.

The works here were well executed: the contractor cut down the face of the excavation, and loaded the spoil into wagons; trains of these wagons were constantly in motion, being drawn by locomotives obliquely up the slope of the hill, and thence to spoil-banks at some distance on the west side of the canal. Some dredging machines were also employed to deepen the channel; the

soil thus raised was discharged into wagons and hauled up the bank. The amount of work done here was very great, as the sand-bank or ridge extended about 5 miles.

To the north of the sand-bank the canal entered the beds of some lakes—the soil of which was but a few inches above the Mediterranean. Here, in places, the soil had evidently a disposition to slide into the canal; as the trifling load of an embankment, sufficiently high to cover the fresh-water pipes, had forced the bank out, in spite of some piles and sheeting, which had been driven and fixed to support it. This sort of work extended the greater part of the remainder of the distance to Port Saïd, about 10 miles from which the canal entered Lake Menzaleh, a shallow sheet of salt water, through which the line was marked by slight embankments, distant apart the full width of the canal. At several points between the deep-sand cutting and the shore of Lake Menzaleh, the canal was opened to its full width. Dredging machines were employed both to widen and deepen it, and a great amount of activity and much skill were developed at this place.

The dredging machines were well put together. They were worked by powerful engines, and a variety of expedients had to be devised for the purpose of adapting them to the work they had to perform in lifting the spoil from a great depth, and discharging it at a point above the engine.

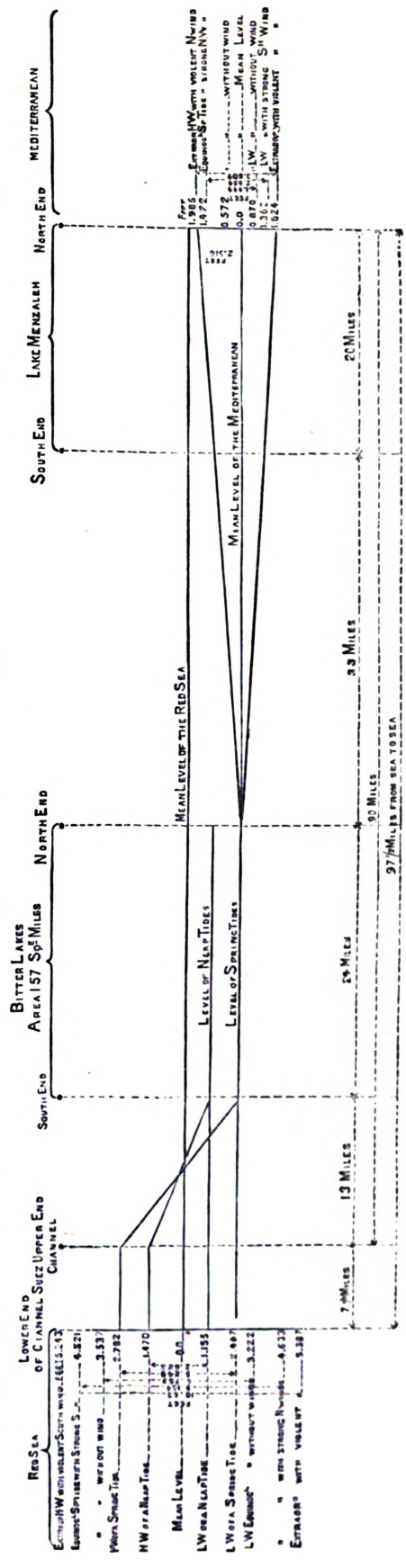
The main work at Port Saïd, Fig. 1865, was the jetty, or breakwater, which protects the port against the action of the north-westerly or prevailing winds. This jetty is formed of blocks of concrete, rectangular in form, and weighing 20 tons. Experience has shown that a block of this size (10 cubic mètres) and of this weight is sufficiently massive to withstand the action of the heaviest sea. The concrete is composed of sea-sand, dredged from the harbour, and of good hydraulic lime procured from Marseilles, the proportion of lime to sand being about 350 lbs. of the former to a cubic mètre of the latter, or about 1 to 13. Sea-water is used to mix the ingredients, which are well worked and amalgamated in mills, ten of which were driven by one steam-engine. The mixture was poured into cases, or frames, of wood, where it was allowed to remain four days; the cases were then removed, and the blocks subjected to the influence of an Egyptian sun for two months, by which time they became solid enough to withstand the action of the sea. Each mill turned out three blocks a day.

The contractor engaged to furnish the blocks, and to deposit them at appointed spots, for 400 francs a block.

The mass will, of course, stand at a much steeper slope than it would were the blocks of smaller dimensions, and there will be a large space between the blocks, which will eventually be filled with sand drifted in by the sea.

The Suez Canal was officially opened on the 17th of November, 1869. At that time fifty ships had passed from the Mediterranean to the Red Sea, or *vice versâ*. From the 1st to the 17th of February, 1870, nineteen vessels, or a little over a vessel a day, went through from one sea to the other. The successful completion of this great work places its engineer, M. de Lesseps, high among the engineers of our time. In France he holds a position similar to that held in America by W. J. McAlpine, or to the one that John Scott Russell should hold in England. See BARRAGE. CONCRETE MACHINE. DREDGING MACHINES. LOCKS AND LOCK-GATES. RIVERS.

*Works relating to Canals* :—Belidor, 'Architecture Hydraulique,' 4 vols., 4to, Paris, 1737–53. Lalande, 'Des Canaux de Navigation,' folio, Paris, 1778. Fulton, 'On Canal Navigation,' 4to. 1796.



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CANDLES. Fr., *Chandelles, Bougies;* Ger., *Kerze;* Ital., *Candele;* Span., *Velas.*

In its natural state, fat of animals is always associated with cellular tissue and other foreign matters, which must be separated before it can be used as candle stock.

In the process called *dry melting*, much practised by small manufacturers, the rough suet is cut into coarse pieces and exposed to the action of a moderate heat. By the more recent processes, the fat is not exposed to heat till it has been subjected to certain mechanical and chemical appliances, for the purpose of destroying the tissues. The first-named method possesses this decided advantage, namely, that the residue or cracklings can be profitably used as food for hogs, fowls, and so on. There is, moreover, an economy in fuel, while the simplicity of the process commends itself to the notice of inexperienced manufacturers. Disadvantages, on the other hand, arise: an obnoxious smell emanates from the heating of rough tallow which has been collected and suffered to remain till it has become rancid, and the cellular tissues, blood, or other portions, advanced towards putrefaction. Fat from animals recently slaughtered does not, however, yield any very unpleasant effluvia. Another and more important disadvantage, in an economical point of view, is found in the smaller amount of fat obtained, as portions always remain with the cracklings when heated in this manner. The first care of the chandler should be to impress on the mind of his tallow merchant the importance of a more careful treatment of the rough suet than is generally observed by the butcher. The fat ought to be freed from the membranous and muscular parts, then cut into thin slices and hung up in a cool place, *not heaped up while yet warm.* By operating thus, the disagreeable odour existing before melting, and increased during the process to an unbearable degree, can, at least, be delayed for several days.

First, the fat is chopped, for which purpose cutting machines are often used similar to the *straw-cutting table;* sometimes a thin, sharp-edged mince-hatchet is employed, about 2½ ft. in length. This is held with both hands, and the fat, spread out on a beech block, is chopped into small pieces in all directions. A third instrument is a kind of stamp trough with muller, having a sharp blade in the form of an S, a contrivance frequently adopted for cutting beets. A more desirable and valuable instrument, however, is the ordinary rotary sausage-cutter. The fat is then placed in melting caldrons (hemispherical in form, and in this country made of cast iron), which are heated by open fire. These caldrons are covered with movable tin-plate hoods, so adjusted that, by means of pulleys, ropes, and counter-weights, they can be easily raised or lowered, whilst at the same time they serve to carry off the offensive vapours arising from the heated fat. Water is sometimes mixed with the fat in the caldrons, and this addition is specially beneficial when the fat has been long kept during the summer months, and thereby lost its natural moisture by evaporation. By gradually raising the temperature in the pan, the fat runs from the cells, and the whole is kept boiling from 1 to 1½ hour. The mixture of water with the fat-bubbles imparts to the liquid a milky appearance, but as soon as the water is volatilized the fat becomes clear. During the whole operation of melting and boiling, the ingredients must be constantly and thoroughly stirred in order to keep the fat and cracklings in incessant agitation, otherwise pieces of unmelted suet, coming in contact with the sides or bottom, would become scorched and acquire a brownish tint, of which the whole melting would necessarily partake. Scorched tallow is not very readily whitened. For separating the melted fat from the cracklings, it is ladled off from the caldron into a fine willow basket, or a copper box perforated at the bottom with innumerable small holes, set over large copper coolers, and allowed to remain undisturbed till all foreign matters have settled down. Before it congeals, it should be transferred into small wooden pails.

This operation is continued so long as the cracklings yield any fat; and during the process the heat must be maintained at a moderate temperature, to avoid scorching the materials. When the cracklings begin to harden they acquire a darkish tint, and hence are said to be *browning.* They are then pressed, and the fat thus obtained possesses somewhat of the brown colour of the cracklings, but not so much as to render it unfit for use as soap stock; it may, consequently, be mixed with that which has spontaneously separated while heating.

*New Methods of Rendering.*—The complaints of parties residing in the neighbourhood of candle and soap works, in consequence of the offensive effluvia disseminated by these establishments, have led to the invention of new apparatus, as well as to the introduction of new processes of rendering, until an entire reformation has resulted in the melting process, which we propose briefly to describe, long experience having demonstrated their utility.

No doubt the apparatus invented by d'Arcet, of Paris, in 1834, and introduced by the board of health of that city, has been tested in other places, where it did not interfere too much with the workmen's freedom of action, and the ready supervision of the melting process. As it is, moreover, applicable and may prove serviceable in other branches of manufacture, we here offer a few remarks relative to this invention.

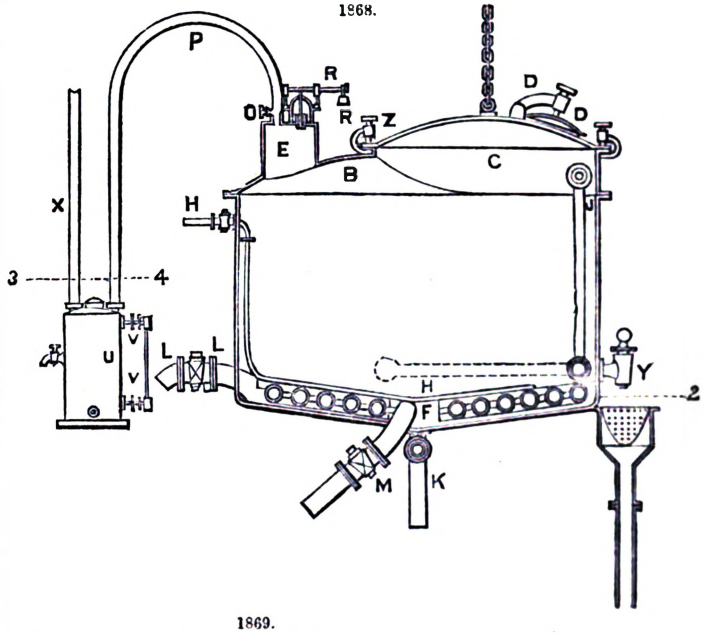
One essential and valuable feature in his invention is his suggestion for conducting the rising vapours, consisting chiefly of hydrogen and carbon, through channels under the grate of the rendering pan, and using them as fuel. The pan is also covered with a strong iron plate, the front third of which can be lifted by means of a knuckle whenever it is necessary for stirring, filling, or emptying the kettle. D'Arcet was likewise the first who employed certain chemicals for the purpose of neutralizing or destroying the noisome effluvia arising from the pans. His propositions are found to be, as yet, the most valuable in use. In the process recommended by him, 50 parts,

by weight, of diluted acid (oil of vitriol) are first put into the kettle, then 1000 parts, in weight, of chopped fat are gradually added in four equal portions; and lastly, 150 parts of water, to which 5 parts, in weight, of sulphuric acid of 66° B. have been previously added. The whole is next heated. Under the influence of the acid, which partly destroys, partly solves the membranes, the rendering of even greater amounts of fat is effected in 1¼ to 2½ hours; two hours, however, are seldom required. The inventor's proposition of using acids was made when pans were heated by the direct action of the fire; but now, for various substantial reasons, steam is more generally employed. This, however, does not prevent the gases arising from the pans being thrown into the furnace and thereby aiding combustion. It is obvious, moreover, that in the boiler of d'Arcet, stirring, as well as filling or emptying the contents of the pan, cannot be accomplished so readily as in an open pan; nor can these processes be performed without opening the covers, when the noisome vapours escape into the room, to the annoyance of the operators. To obviate this, a contrivance similar to that used by distillers in the mashing process could be introduced with decided advantage of comfort, as well as of certainty, for keeping up the necessary motion, to prevent adhesions to the sides or bottom of the vessel, and consequent incidental scorching.

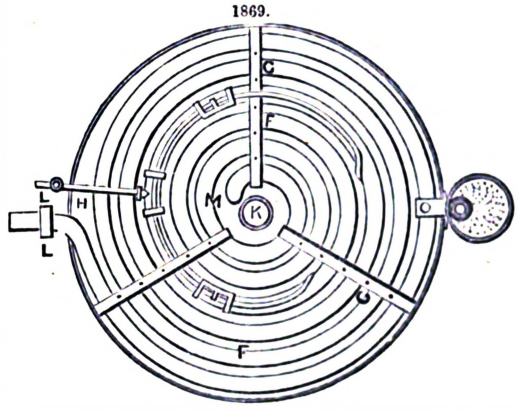
The same may be said in regard to the pan for boiling fats lately patented in this country by W. H. Pinner, who yet claims the conducting of the noxious vapours into the fire as a *novelty*.

*Wilson's Process* has first been described by Morfit in his 'Treatise on the Manufacture of Soap and Candles.' The chief feature of this process is to steam the rough suet for ten or fifteen hours in a perfectly tight tank, under a pressure of 50 lbs. to the square inch, or more when lard is being rendered. A higher pressure, according to Morfit, is not profitable, for, though expediting the process, it produces an inferior quality of fat. No chemicals are used. The apparatus consists of an upright cylindrical vessel, made of strong boiler-plates, tightly riveted together. Its diameter is about two and a half times less than its height, and its capacity amounts to 1200 to 1500 gallons. It has a false bottom or diaphragm, below this a pipe enters, which is connected with an ordinary steam-boiler. There is a man-hole at the top, through which the vessel is filled with the rough suet or lard to within about 2½ ft. of the top. By a safety-valve, the pressure can be regulated. There are also some try-cocks, by which the state of the contents can be examined; if the quantity of condensed steam in the tank be too great, it will be indicated by the ejection of the fatty contents at the top one. There is, moreover, a regulating cock at the bottom for drawing off the condensed steam, as well as cocks in the side of the digester, by which the fatty materials can be drawn off. Through a hole made in the diaphragm, which can be shut and opened at will, the residual matters can be let out.

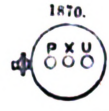
1868.




1869.




1870.




*Fouché's Process* is one of the most perfect. Fig. 1868 represents a vertical, and Fig. 1869 a horizontal section of the apparatus, as used by the inventor, after the line 1—2 in Fig. 1868. Fig. 1870 is a transverse section after the line 3—4 in the same figure. The vessel has a copper dome B, fastened by rivets. In this dome is a hole C for introducing fat, having a cover, which may be lifted by a chain going over a pulley, and the margin of the cover may be fastened to the vessel by clamps. This cover has a hole for observing the inside, which can be shut by a valve fastened to the lever D. E is a cap on the dome with the eduction-pipe for vapours, and P P is a safety-valve, with a counter-weight R. There is, moreover, an outer valve for the passage of air, either when filling or emptying the vessel, as well as a box for a thermometer. The vapours escaping through P

(which may be opened by the faucet O), pass into U for the purpose of being condensed there, or, when not condensed, for escaping through X. F is a worm, which fastened to the stays G, Fig. 1869, lies on the bottom of the vessel. Through L L steam is introduced from a boiler, and through M passes back into the same boiler. H H is a small pipe entering into the vessel A, through which steam also passes into the vessel, mainly for the purpose of keeping the melted fat in agitation. J is a tube, having a sieve at its upper end, and a movable crank below, by which it is fastened to the faucet Y. If the vessel is being emptied, the tube J is gradually let down until its upper part, with the sieve, reaches the bottom. The fat is then passed through J and Y, and through a fine sieve outside the vessel, which acts as a filter. In this, 1000 lbs. are first introduced with 80 lbs. of water; $2\frac{4}{10}$ lbs. of sulphuric acid of 66°, previously mixed with 16 lbs. of water, are then added. Steam is next turned on, which, as described, passes from the generator through the worm, and must have a tension of three atmospheres, or a temperature of 255° F. In the vessel, however, a tension of $1\frac{1}{2}$ atmosphere is sufficient, and when this is reached, the safety-valve is no longer charged with weights. The vapours formed in the vessel are conducted through X into the hearth of the steam-boiler furnace, so that all the noxious odours (which, however, by the action of the sulphuric acid, are diminished, but not destroyed) are thus conveyed from the working-rooms.

*Evrard's Process.*—In its features, the apparatus used by this inventor very much resembles that of Wilson. The process, however, is based on the application of caustic lye, in the proportion of 25 gallons (each containing $\frac{1}{10}$ to $\frac{1}{7}$ lb. of solid caustic soda) to every 250 to 350 lbs. of rough tallow. It is the object of the application of the lye, as in d'Arcet's process, to dissolve the membranous parts, so that no preliminary mincing be necessary. For boiling the fat, steam is employed. As the alkaline lye is heavier than water, it will also, after the boiling is completed, more easily subside. It is then drawn off, and the fat left in the tank is again boiled with successive portions of fresh water, for the better separation of which, this compound is left for twenty-four hours in a warm liquid state before being drawn off into the coolers.

*Stein's Process.*—A mixture of slacked lime and small pieces of fresh-burnt charcoal is prepared, and spread upon a coarse cloth stretched over a hoop, of 2 in. in depth, and the circumference corresponding with the size of the pan. During the process of rendering, it is securely adjusted by suitable catches above the pan. The rising vapours from the latter, in necessarily passing this chemico-mechanical arrangement, are said to be entirely absorbed, so that thus all cause of complaint against tallow factories as health-destroying nuisances would be effectually removed.

*Clarifying Tallow.*—By mere melting and straining we do not obtain a fat entirely free from admixture of fine, undissolved substances. For separating these substances, therefore, it must be clarified. This is done by remelting it in water, either on free fire or by steam. Generally, no more water than 5 per cent. is taken, and stirred well with the fat till the mixture becomes emulsive. The whole is then allowed to rest, without further heating, till the water has separated, when the fat may be drawn off, or dipped off. Sometimes, in order to conceal the yellowish tint, a very little blue colour is added to the clear fat, consisting of indigo rubbed finely with some oil, of which a few drops are sufficient even for large quantities. The process of clarifying is occasionally repeated.

At the line of demarcation between the water and fat, a grey slimy substance is often perceptible, and the liquid itself is turbid. Instead of pure water, some tallow-melters take brine or solutions of alum, saltpetre, chloride of ammonium, or other salts. According to Dr. Orazio Lugo, these agents have no chemical action upon the fats, but simply induce a more rapid settling of the impurities and water, principally when strong agitation is used.

*Hardening of Tallow by Capaccioni's Process.*—In 1000 parts of melted tallow, 7 parts of sugar of lead, previously dissolved in water, are stirred, during which process the mass must be constantly agitated. After a few minutes the heat is diminished, and 15 parts of powdered incense, with 1 part of turpentine added, under constant stirring of the mixture. It is then left warm for several hours, or until the insoluble substances of the incense settle to the bottom. The hardening is produced by the sugar of lead, yielding a material similar to the stearic acid, while the incense is improving its odour; it is also said that by this treatment the guttering or running of the candles is entirely prevented.

*Cassgrand's Process for Bleaching Wax.*—By this process, the bleaching of the wax by the sun and air is not prevented, but much time saved. The inventor first melts the wax with steam, which together pass through long pipes, so that a large surface becomes exposed to the steam. After traversing the pipes, it is received into a pan with a double bottom, heated by steam; it is therein treated by water, left quiet for some time until its impurities are settled. It is then forced anew through the pipe together with the steam, washed a second time, and, if necessary, this process is repeated a third time. Probably water is absorbed by the wax, thus rendering it more easily bleached. The following is the arrangement of a bleachery:—

Stakes or posts are driven into the ground, and 2 ft. from the ground bag-clothes are stretched over them, or table-like frames are made from strips, and cloth stretched over the frames in the same manner as a sacking-bottom is stretched over a bedstead, care being taken to fasten the ends of the cords to the posts sufficiently firm as to prevent them loosening by the wind. This done, the wax ribbons are spread upon the cloth in a thin layer. It is important that the place selected for this arrangement be so that the sun's rays may have full play upon the exposed wax, but at the same time protected from the prevalent winds. The ribboned wax is daily turned over, in order that fresh portions of it may be affected by the sun; and should it not be sufficiently moistened by the dew or rain, soft water is poured over it. When it is not gradually becoming whiter, but still continues yellow upon the fracture, it is remelted, ribboned, and again bleached. The continuance of the bleaching process necessarily varies, depending, as it does, upon the weather; often one exposure to the sun and air suffices to bleach it, and no remelting is requisite. Four weeks are generally sufficient. The bleached wax is finally fused into cakes or square blocks,

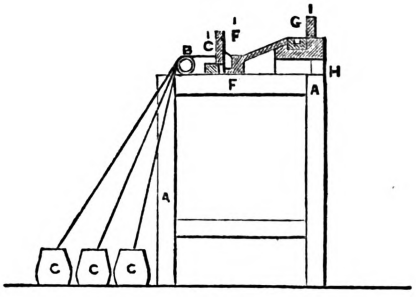
previously moistening the moulds. As fast as the wax congeals, the cakes are thrown into a tub of clean, cold water, and then taken out and spread upon a pack-thread sieve for draining. Eventually, they are dried and packed in boxes for the market, the loss being from 2 to 8 per cent.

*Wicks.*—In the present day we designate the wicks as twisted and plaited; the former, loosely twisted, and the fibre presents the appearance of a spiral similar to the separate strands of a rope; the latter, now generally adopted for most kinds of candles, is made by interlacing and crossing the strands of the wicks in the same manner as plaiting straw of bonnets. Common wicks are simply an aggregation of several loosely-twisted threads forming one general cord of many fibres. This is effected by the ball winding machine, an apparatus of a very simple construction.

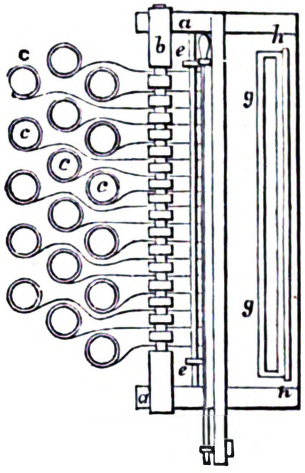
For *cutting* wicks, Sykes's Apparatus is in very general use, especially for tallow-candle wicks, which must be soaked with tallow at one end.

Fig. 1871 represents a vertical, and Fig. 1872 a horizontal view of it. *c c* are spools on which the wicks are wound. *b* is a roller with grooves cut around it, by means of which the wicks are conveyed into the clamp *d*, represented in Fig. 1873 on a larger scale, and as seen from the side.

1871.




1872.




1873.

It consists of two wooden frames, which are made tapering from the middle towards the end. On each side there is a feather of steel attached, for the purpose of holding the frames, with a space between them, which may be diminished by sliding the feathered clamps *e e* towards the middle, or increased by drawing them towards the end. Immediately behind the clamp there is a cutting apparatus, consisting of an immovable *f'* and a movable blade *f*, with a handle. *g* is a small vessel filled with liquid fat (which may be kept from solidifying by steam), and a board *i* lying on the lathe *h*.

The use of the apparatus is as follows:—The ends of the wicks, wound upon the spools *c c c*, are passed through the frame *d*, properly tightened by the clamps *e e*, so that all the wicks are kept firm. The knife *f* of the cutting apparatus is then lifted out of the way; the frame, with the wicks enclosed, is drawn backwards to the vessel *g*, and the ends of the wicks dipped in the melted fat; this done, the fat-soaked ends are drawn farther back and placed under the weight I, which holds them firmly while the clamps are loosened on the frame, and this returned to its first-described position and again tightened. The knife is next used, cutting all the wicks off at a stroke, then elevated, and the process repeated till a sufficient number of wicks are cut.

The thickness of the wicks, we may here remark, varies according to the diameter of the candles and the material of which they are made. The number of the cotton threads requisite to form a wick also varies according to their firmness. Scarcely two chandlers, however, observe the same rules in these respects. The yarn is composed of a slack-twisted cotton thread, No. 16 generally for plaited, and smaller, such as 8–12, for common wicks.

Bolley has published the appended index relative to the thickness of wicks. The yarn employed is No. 16.

| | | | | |
|---|---|---|---|---|
| For tallow candles, 8 per lb., the wick contains | | | 42 | threads. |
| ,, | 7 | ,, | 45 | ,, |
| ,, | 6 | ,, | 50 | ,, |
| ,, | 5 | ,, | 55 | ,, |
| ,, | 4 | ,, | 60 | ,, |

These wicks, composed of ten, twelve, or even sixteen cords, are very loosely twisted, and form a kind of hollow tube.

For stearic candles, three-corded plaited wicks are generally used, smaller in size and of finer yarn. As, for instance—

| | | | | |
|---|---|---|---|---|
| Stearic candles, 4 per lb., the wicks consist of | | | 108 | threads. |
| ,, | 5 | ,, | 96 | ,, |
| ,, | 6 | ,, | 87 | ,, |
| ,, | 8 | ,, | 63 | ,, |

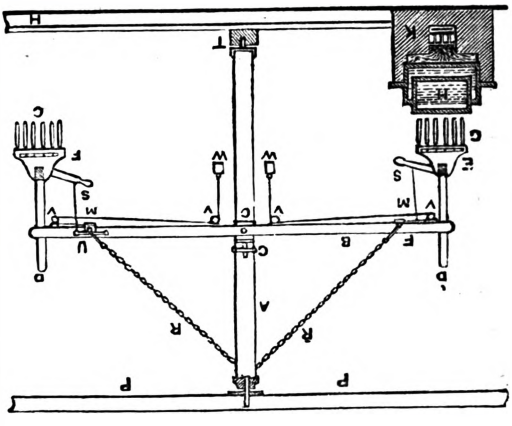
*Preparing Wicks.*—This is done by the so-called *wick-mordants*, by means of which they are less combustible, especially those for stearic acid, and composite candles prepared. For this purpose, compounds composed of solutions of ammoniac salts, of bismuth, of borates, or boracic acid, are used. Some of the receipts given in the journals and books devoted to technology are good as far as the *quality* of the substances is concerned, but not as regards the *quantity*. The recommended solutions are generally too strong. This may be said most assuredly of the following (Smitt's) preparations for wax-candle wicks. He recommends 2 oz. of borax, 1 oz. of chloride of calcium, 1 oz. of nitrate of potash, 1 oz. of chloride of ammonium, to be dissolved in ¾ gallon of water, and afterwards dried.

A simple and cheap mordant for wicks consists in a sal-ammoniac solution of 2° to 3° B. This concentration is strong enough, and if a weaker one be used, a spark will remain on the wick after the candle has been blown out, and burning down to the fat, make relighting more difficult. Before moulding is performed, the wicks, having been saturated, are thoroughly dried in a tin box, surrounded by a jacket, in which steam is introduced. Instead of the sal-ammoniac, phosphate of ammonia is used in some factories. A very good mordant is also a solution of $2\frac{4}{10}$ oz. boracic acid in 10 lbs. of water, with ½ of an ounce of strong alcohol, and a few drops of sulphuric acid. Some mordants, we are aware, have become unpopular. The fault is in the nature of the crude cotton, which does not always readily become moistened; consequently, from not having completely imbibed the mordant, portions of the thread remain unsaturated, and are not equally combustible with the others. An admixture of alcohol will possibly remedy this defect, inasmuch as cotton is easier moistened in diluted spirit than in pure water.

*Dips.*—These candles are made by stringing a certain number of wicks upon a rod, and dipping them in melted tallow repeatedly. Though made in large quantities, they are only manufactured in comparatively small establishments. The process is very simple; it is as follows:—The clarified and remelted tallow is poured into a tightly-joined walnut or cherry trough, 3 ft. long by 2 ft. wide, and 10 to 12 in. wide at the top, gradually diminishing to 3 or 4 in. at the bottom. A handle is fixed on each end for its easy removal, and when not in use it is closed with a cover. The operator commences by stringing sixteen to eighteen wicks at equal intervals on a thin wooden rod, about 2½ ft. long, and sharpened at the ends. He then takes ten or twelve such rods and dips the wicks rapidly into the fluid suet in a vertical direction. This suet should be very liquid, in order that the wicks be soaked as uniformly as possible, after which the several rods are rested on the ledges of the trough, when, if any of the wicks be matted together, they are separated, and the rods so placed on a frame, having several cross-pieces, that the uncongealed tallow from the wicks may drop down, and while this is going on, which continues till the tallow is cooled and solidified, the operator is engaged in preparing another batch of rods. The fat in the trough, meanwhile, is so far cooled that in immersing the first dip again a thicker layer will adhere to the wicks. It is considered, we may observe, that when the suet solidifies at the sides of the vessel, the temperature is the most convenient for the object in view. It is, moreover, sometimes necessary to stir the ingredients to produce a uniform admixture, and in such cases much care should be taken so that no settlings be mingled with the mass, whilst by the addition of hot tallow any desired temperature may be obtained. The tallow on the wicks between each dipping becomes so gradually hardened, that at the third or fourth immersion new layers necessarily solidify; as a natural consequence of the method of dipping, the lower ends of the wicks become thicker than the upper, to remedy which the lower ends are again put into the melted fat for a few minutes, when the heat, as a matter of course, diminishes their dimensions. The process of dipping is continued until the candles acquire the requisite thickness. The conical spire at the upper end is formed by immersing *deeper* at the *last* dip, and if, eventually, the candles are too thick at the lower end, they are held over a slightly-heated folded copper sheet, so that the fat may melt, but not be wasted.

For the purpose of saving time, many mechanical arrangements have been devised and completed, one of the most useful and used of which, involving the least outlay and requiring only one operator, is the EDINBURGH CANDLE-WHEEL, Fig. 1874.

1874.



The following is a description of it:—A strong vertical post A is mounted on pivots, resting on a block T, and attached at the top in a beam P P, so that it can revolve freely on its centre. In the upright post A, six mortices are cut at short distances from each other, and crossing one another at an angle of 60°. Each of these six mortices receives a bar D, which swings freely on a pin C, run through, the centre of the bar E and post A. At the extremity of each bar is suspended a frame E, containing six rods, on each of which are hung eighteen wicks, making in all 1296 wicks on the wheel. As the bars B are all of the same length, and loaded with nearly the same weight, it is obvious that they will all naturally assume a horizontal position. In order, however, to prevent any oscillation of the machine when turning round, the levers are kept in a horizontal position by means of small chains R R, one end being fixed to the top of the upright shaft, and the other in a small block of wood M, which exactly fills the notch F. Notwithstanding its appearance, the machine is very easily turned round, and, when in motion, each

port, as it successively passes over the tallow-kettle H, in its water-bath, mounted on a furnace K, is gently pressed downwards by the handle S. By these means the wicks are regularly immersed in the tallow, and the square piece M (when the handle S is pressed down) is thrown out of the notch by the small lever O, inserted in the bar B. In order that, when the operator raises the port, the piece M may return to its proper position, a cord is attached to it, passing over the pulleys V V, and regulated by the weights W W. In the bars D several holes are bored, by means of which they may be heightened and lowered at will.

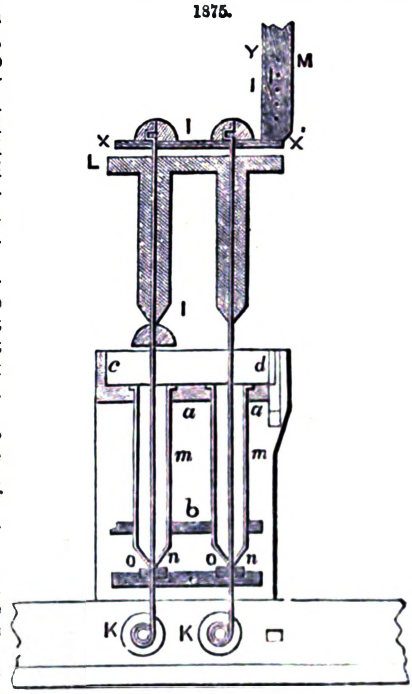
It may be readily perceived, therefore, with what expedition the whole operation is performed (and that too by one operator), the ports being not unnecessarily removed after each dip, and the process of congealing being much accelerated, as the candles are kept in constant motion through the air. In moderately cool weather not more than two hours are necessary for a single person to finish one wheel of candles of a common size, and that if six wheels are completed in one day, 7776 candles will be manufactured in that space of time by one workman.

*Moulds.*—For moulding, besides the common metal moulds (a mixture of tin and lead), moulds of glass are sometimes used. The former are slightly tapering tubes, varying in length and dimensions according to the size of the candle to be manufactured, and, when required, are arranged in regularly perforated wooden frames or stands, with the smaller end downwards, forming the upper or pointed part of the candle. At this smaller end, the wick, previously saturated in melted fat, is inserted, filling the aperture, and, passing up the centre, is fastened perpendicularly at the opposite, that is, the upper end of the tube, to which is attached a movable cover. The melted fat is then poured in, generally with a small can, but a tinned iron syphon is better. It is requisite that the tallow should *completely* fill the mould, that it should remain uncracked on cooling, and should be easily removable from the moulds. This can, however, only be obtained when the fat at the sides cools more quickly than that in the interior, and when the whole candle is rapidly cooled. A cool season is, for this reason, far better; but a certain condition of the tallow, namely, that which it possesses at a temperature very near its melting-point, is absolutely necessary. According to Knapp, candle-makers recognize the proper consistence of the tallow for moulding by the appearance of a scum upon the surface, which forms in hot weather between 111° and 119° F., in mild weather at 108°, and in cold about 104°. The tallow is usually melted by itself, sometimes, however, over a solution of alum. The candles are most easily removed from the mould the day after casting, to be cut and trimmed at the base.

*Moulding.*—Moulding by hand is a very tedious operation, and only practised in the smaller factories; in more extensive establishments, where economy of time and labour is a consideration, machinery is employed.

*Kendall's Moulding Apparatus.*—Fig. 1875 represents a vertical transverse section through one of the mould-frames, exhibiting the candles drawn from the moulds. Fig. 1876 represents a top view of a row of moulds, showing the clamp in place ready to centre the wicks. The moulds are mounted upon cars, for being carried from place to place as required, each capable of conveying several dozens, which are heated to about the temperature of the melted fat by running the car into an oven. The moulds thus heated are carried by cars to a caldron containing the melted fat, with which they are filled. The car is then attached to one of the empty trucks and allowed to remain till the candles are cooled, when it is moved to an apparatus, by means of which the candles are drawn and the moulds re-wicked, and again ready to be heated and filled.

1875.




To facilitate the transference of the moulds to different parts of the room, the cars on which they are mounted are carried about on trucks fitted with rails at right angles to the track on which they run; so that the car with the moulds can be carried forward or back by the truck, and run to the right or left on its own wheels upon lateral tracks at will.

In Fig. 1875, *m m* represent moulds mounted on two horizontal boards *a* and *b* (in which round holes are cut) and tightly screwed at the upper end, around which a thin wooden frame is attached, three-fourths of which is firmly fastened, whilst the other one-fourth forms a slide. The lower end of the moulds rests on pieces of vulcanized india-rubber *o*, let into the cross bar *e*; each piece of india-rubber being pierced with a hole somewhat smaller than the wick, and as the wick is passed through this hole, the latter compresses it so tightly as to prevent the fat from leaking out. In like manner, the leakage is prevented between the bottom or tip *n* by the pressure of the mould upon the india-rubber. The spools K hold the wicks firmly and centrically secured by clamps, as seen in Fig. 1876. On the ledge *c*, moreover, of the bottom *a* there are four pins *i*, which tighten the clamps *j*, Fig. 1876, by means of small holes *g h*. On one side F of the clamp there are also toothed jaws, in which the wicks fit exactly, that is, they are thus kept vertical and in the *centre* of the moulds.

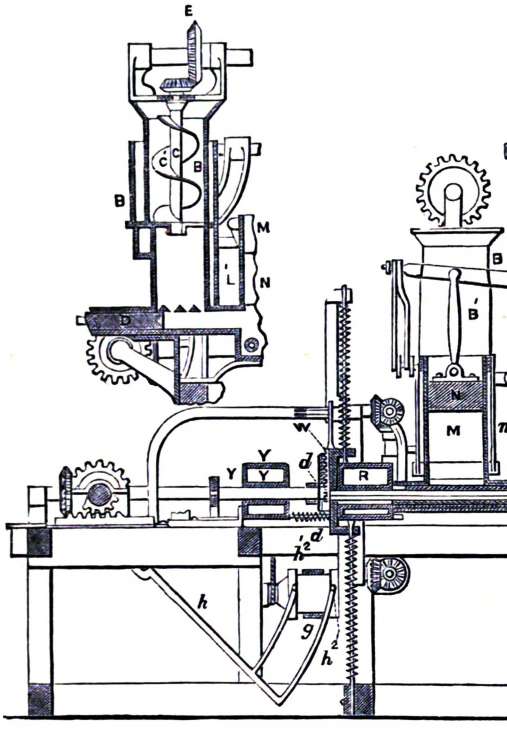
The construction of the clamp, Fig. 1876, is such that the arm working upon a joint at *q*, and

being brought against the arm F, falls into a groove made in its length, so as to press and kink the wicks in said groove, and fasten them firmly there by means of the spring catch K. The object of this is, that in raising the candles from the moulds by this clamp they shall not slip nor move. As the candles are lifted out of the moulds (as in Fig. 1875), the wicks are drawn after them from the spools K, and are then clamped in position in the manner described. The wicks are next cut off above the lower clamp, the candles with the clamps removed, when, by sliding off the spring catch K, the spring S, between the jaws *t t*, causes the arm *j* F to separate and release the wicks.

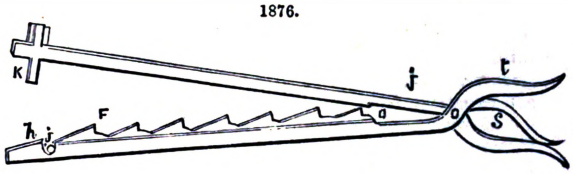
*Composite Candles.—Cérophane.*—The mode for manufacturing this block is the following:—Melt together, over a water-bath, 100 parts of stearic acid, and 10 to 11 parts of bleached beeswax; but, to ensure success, the mixture must remain over the bath from 20 to 30 minutes, and without being stirred or agitated. At the end of that time, the fire is to be extinguished, and the fluid allowed to cool until a slight pellicle is formed on the surface, when it is cast direct into the moulds, previously heated to the same temperature, but with the precaution of avoiding stirring the mixture, as a disregard of it would cause opaqueness of the mixture, instead of transparency

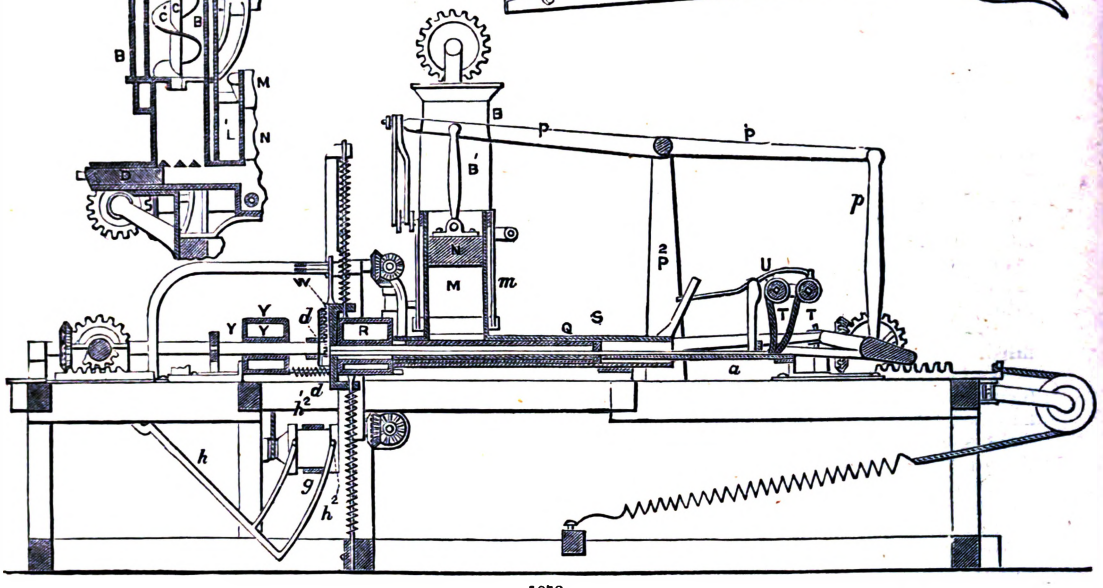
*Transparent Bastard Bougie*, by Debitte, of Paris.—For 100 lbs. of stock take 90 lbs. of spermaceti, 5 lbs. purified suet of mutton, and 5 lbs. wax; melt each separately over a water-bath, and to the whole, when mixed together, add 2 oz. of alum and 2 oz. of bitartrate of potassa in fine powder, and while stirring constantly, raise the heat to 176° F., then withdraw the fire and allow the mixture to cool to the temperature of 140° F. When the impurities subside, the clear liquid must be drawn off into clean pans. For quality and good appearance, candles made of this cooled block are more than proportional to its cost. Morfit recommends to substitute plaited wicks for the foregoing mixture to the wicks generally used for composite candles, and to prepare them by previously soaking in a solution of 4 oz. borax, 1 oz. chlorate of potassa, 1 oz. nitrate of potassa, and 1 oz. sal-ammoniac, in 3 quarts of water. After being thoroughly dried, they are ready for moulding.

1877.




1876.




1878.

*Diaphane.*—It is, like the block for cérophane, an invention of Boilot, and made by melting together, in a steam-jacket, from 2½ to 17½ lbs. of vegetable wax, 1½ to 10½ of pressed mutton tallow, and 22 to 46 lbs. of stearic acid. Both the latter and the vegetable wax are the hardening ingredients. By changing the proportions between the above limits, a more or less consistent mixture may be formed. As concerns the moulding, it is performed in the same manner as for stearic-acid candles.

*Parlour Bougies, similar to Judd's "Patent Candles."*—Although not bougies, a name which, properly speaking, is only applicable to candles of wax alone, the similarity of these candles to those of wax has induced the aforenamed title for them. According to Morfit, their mode of manufacture is as follows:—Melt slowly, over a moderate fire, in a well-tinned copper kettle, 70 lbs. of pure spermaceti, and to it add piecemeal, and during constant stirring, 30 lbs. of best white wax. By increasing the proportion of wax to 50 lbs., the resulting product is much more diaphanous; however, the bougies moulded of this mixture are not as durable as candles made exclusively of wax. They are tinted in different colours. For red, carmine or Brazil-wood, together with alum, are used. Yellow is given with gamboge, blue with indigo, and green with a mixture of yellow

and blue. Sometimes the bougies are perfumed with essences, so that in burning they may diffuse an agreeable aroma.

A still more transparent and elegant bougie is made by adding only 6½ lbs. of wax to 100 lbs. of pure, dry sperm, and the candles made of the block formed in these proportions resemble very much the "patent candles" of Judd.

*Composite Candles.*—The block for these candles is made by adding a portion of hot-pressed cocoa-stearine to stearic acid of tallow. It is an excellent and economical mixture, in which the red, carbonaceous flame of the latter ingredient is improved in illuminating power by the white and more hydrogenated flame of the stearine.

"*Belmont Sperm.*"—It consists merely of a mixed stock of hot-pressed stearic acid, from palm and cocoa-butters. Palmitic acid coloured by gamboge is called *Belmont wax*.

*Harrison Gambo's Machine for manufacturing Candles*, Figs. 1877, 1878.—B, Fig. 1878, is the receiving-chamber, surrounded by a steam-jacket B B, Fig. 1877, *m* M B', Fig. 1878. The tallow is forced from this receiving-chamber into supply-cylinders L', Fig. 1877, M Q S, Fig. 1878, where it is acted upon by a plunger N, which forces the tallow into the space in front of a tubular plunger. This tubular plunger contains the candle-presser and the wick-tube *a*. The tallow is pressed into the mould R, then ejected from the mould, and the wick-tube drawn back; the wick being held by a clamp *d*, is severed by the drawn shears W. The levers *p p* and the reacting springs repeat the motion. Upon leaving the mould R the candle enters a mould Y, which is surrounded by ice or cold water. From mould Y the candle is forced on to arms $h^2$, $h'^2$, which are operated by levers *h*, and conveyed to an endless carrier *g*. The reels T T are used in combination with the dog U for the purpose of limiting the let-off motion of the wick. $P^2$ is a fixed support; E bevel gear; and C C' feed-screw.

CAOUTCHOUC. Fr., *Caoutchouc*; Ger., *Kautschuk*; Ital., *Gomma elastica*; Span., *Cautchuc*.
See Gutta-percha. India-rubber.

CAPSTAN. Fr., *Cabestan*; Ger., *Spill* (*Schiffswinde*); Ital., *Argano*; Span., *Cabrestante*
See Mechanical Powers, *Wheel and Axle*.

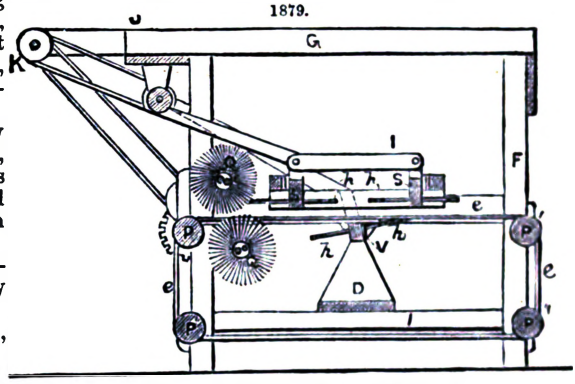
CARDBOARD-CUTTING MACHINE. Fr., *Machine à couper les cartons*; Ger., *Kartenschneidmaschine*; Ital., *Macchina da tagliare cartoncini*; Span., *Guillotina*.
See Paper Machinery.

CARDING ENGINE. Fr., *Machine à carder*; Ger., *Krämpelmaschine*; Ital., *Macchina da cardare*; Span., *Carda*.
See Cotton Machinery.

CARPET-BEATING MACHINE. Fr., *Machine à battre des tapis*; Ger., *Teppichreinigungs Machine*; Ital., *Macchina da battere i tappeti*; Span., *Máquina para apalear*.

The Carpet Beating and Cleaning Machine of G. P. Mitchell, Fig. 1879, is constructed with a shaft K that drives a number of counter-shafts P, upon which endless ropes *e* are arranged.

1879.




The carpet, carried and moved by the ropes *e*, meets with the whips *h*, worked by rock-shafts S, V, and thus the carpet is beaten; it is then passed between cylindrical brushes Q Q, which effect the cleaning and brushing.

The machine is fixed in a framework J, G, F, and may be temporarily placed in a field or an inclosure.

CARRIER. Fr., *Moteur*; Ger., *Mitnehmer*.
See Lathe.

CARTRIDGE. Fr., *Cartouche*; Ger., *Patrone*; Ital., *Cartuccia*; Span., *Cartucho*.
See Ordnance. Small Arms.

CARVING MACHINERY. Fr., *Machine à tailler en bois*; Ger., *Holzschnitzmaschine*; Ital., *Macchina da intagliare*; Span., *Máquina para tallar*.
See Lathe.

CASE-HARDENING. Fr., *Tremper à la volée*; Ger., *Härten, Hartguss*; Ital., *Temperare a pacchetto*; Span., *Acerado por fuera*.
See Anvil. Auger, p. 201. Iron. Steel.

CASEMATE. Fr., *Casemate*; Ger., *Casematte*; Ital., *Casamatta*; Span., *Casamata*.
See Fortification.

CASK MACHINERY. Fr., *Machine à monter les futailles*; Ger., *Maschine zum binden der Fasser*; Ital., *Macchina da far barili*; Span., *Maquinaria para hacer barriles*.
See Stave-making and Cask Machinery.

CASTING AND FOUNDING. Fr., *Fondre*; Ger., *Giessen*; Ital., *Arte del fonditore*; Span., *Fundicion*.
See Founding and Casting.

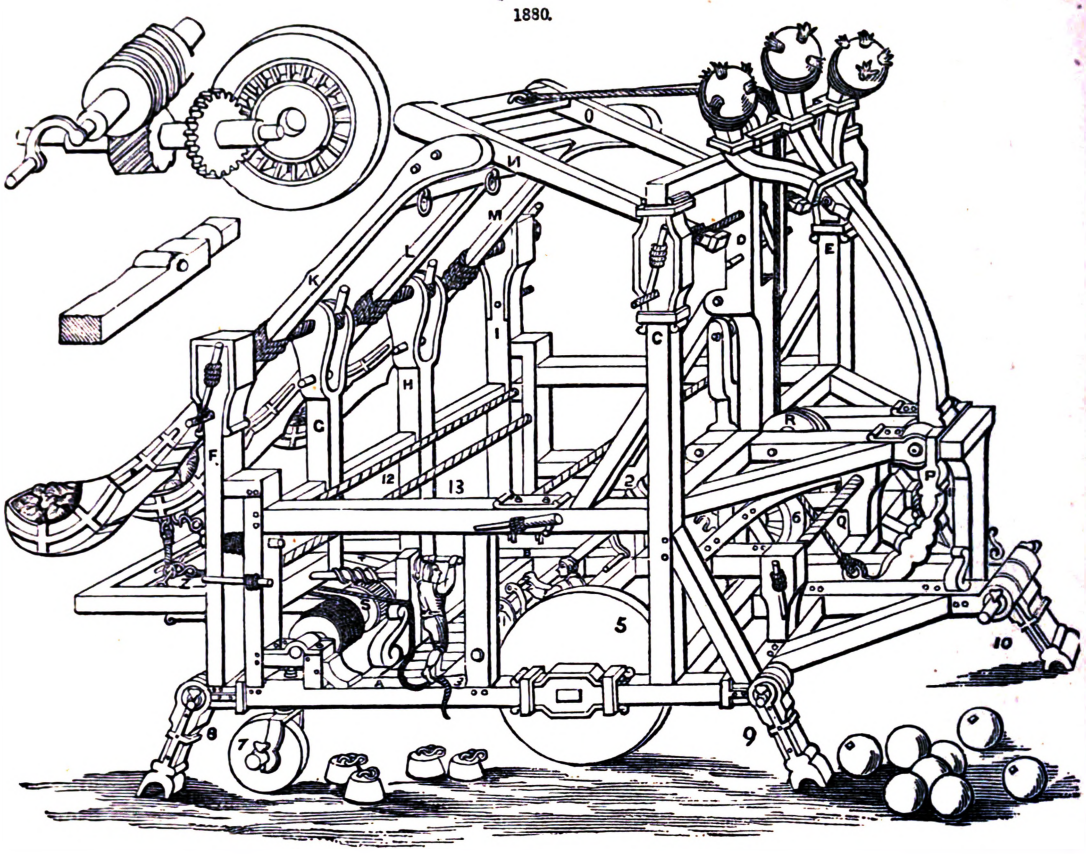
CATAPULT. Fr., *Catapulte*; Ger., *Katapulte, Wurfmaschine*; Ital., *Catapulta*; Span., *Catapulta*.

The engine used by the ancients, Fig. 1880, termed a *Catapult*, possesses several mechanical properties which deserve particular attention.

This engine, says Ramellus, writing in 1620, which we have borrow from the ancients, is of great service in defending a town from assault. Its use is to throw large quantities of stones, iron, balls filled with fire, and other noxious substances upon the enemy. The following is its mode of construction.

Upon a base or platform A B, Fig. 1880, are placed, in a vertical position, seven stout supports C D E F G H I; these supports are joined together and strengthened by horizontal pieces firmly fitted to them in the middle. The arrangement of the several smaller parts, such as wheels, screws, bolts, and so on, will be better understood from the figure. To the tops of the four supports F G H I are affixed, in the manner shown in the figure, three pieces K L M, connected at one extremity by a cross-bar and terminated at the other extremity by a kind of trough or spoon, of a sufficient capacity to contain a considerable quantity of stones or other matter which it is required to throw upon the enemy; the opposite end of each of these pieces is weighted to counterbalance the load of missiles. The pieces themselves being suspended by means of several double cords, great force may be communicated to them by twisting the cords; the force thus obtained is considerably increased by the pressure of the part N O, which is affixed to the three front supports C D E in the same manner as the pieces we have been considering. The part N O is also connected with the lever P by means of a cord attached to its lower extremity. This lever P is designed to throw balls or pots filled with fire, or other similar missiles.

1880.




The mode of preparing the engine for action may be thus described:—A rope is attached by a hook to a ring on the middle receptacle, the other end of which rope is passed round a drum S; this drum is made to revolve by means of the perpetual screw T. The three receptacles are in this way brought down, and the lever P is raised; the operation, by tightening the twisted cords, increasing the recoil. They are then fixed in this position by a bolt Z. The receptacles are now filled with missiles, and the engine is ready for action. When the bolt Z is withdrawn, each of the pieces acted upon by the twisted cords, being liberated, recoils with great force. The ends of the levers carrying the missiles are brought violently against the ropes Q and 12, and the force of the concussion hurls the charge to a great distance.

The engine is removed from place to place by means of perpetual screws and toothed wheels fixed to the spindles of the screws and working into cavities in the two wheels 5 and 6, upon which the engine rests. Two men are thus sufficient to move and guide it. The five feet upon which the engine rests when stationary are firmly fixed into the ground with iron cramps; during its removal from one place to another these are turned up.

The cords should be made of the same material and in the same manner as the counter-bass strings of a violoncello. See Angular Motion. Inertia. Pendulum. Projectiles. Reaction. Velocity.

CATHETOMETER. Fr., *Cathetomètre*; Ger., *Cathetometer*; Ital., *Catetometro*; Span., *Catetómetro*.

See Materials of Construction; *Elasticity of Traction*; *Elasticity of Tortion*; *Elasticity of Flexure*; *Tenacity*; and *Ductility*.

CEMENT. Fr., *Ciment*; Ger., *Cement*; Ital., *Cimento*; Span., *Cimento*.

As the many varieties of cement which have during the last seventy years been more or less used for building purposes are now nearly superseded by the more valuable and better understood Portland and Roman cements, it is deemed unnecessary to describe them, more especially as they are now becoming, if not already, obsolete.

Portland and Roman cements, although frequently used for similar purposes, vary materially in their qualities. The former, rapidly superseding the latter, is an artificial preparation possessing many valuable properties which recent engineering works have been instrumental in developing.

Portland cement is made from an intimate and perfect admixture of chalk and clay, in varying proportions, according to their respective values—that is to say, the relative proportions of carbonate of lime in the chalk, and silica and alumina in the clay—the other chemical constituents being too insignificant for consideration when the suitable kinds of chalk and clay are selected. Generally speaking, a proportion of 20 per cent. of clay may be considered the right quantity, provided it does not contain more than 15 per cent. of ferruginous matter in iron oxides. The best selected materials used in making this cement in England contain the following ingredients:—

| *Chalk.* | | *Clay.* | |
|---|---|---|---|
| Lime | 56·5 | Silica | 68·45 |
| Carbonic acid | 43·0 | Alumina | 11·64 |
| Water | 0·5 | Ca. lime | 0·75 |
| | | Oxide of iron | 14·80 |
| | | Soda and kali | 14·0 |

The method of preparation usually adopted is to combine these two materials in the most intimate and perfect manner. To effect this satisfactorily the whole is reduced to a soluble condition by the aid of water through the agency of different mechanical arrangements, and on the perfection of this process the future success of the manufacture depends; imperfect or irregular proportions of clay or chalk resulting in a cement disastrous to the manufacturer, and dangerous if used in works of construction by the engineer or architect. The mixture is passed into reservoirs, and the water of solution drained off by decantation. After the necessary interval of time has elapsed, the raw material, as it may now be called, is desiccated, and immediately thereafter placed in suitable kilns, where it is decarbonized, and then becomes what is technically termed clinker. From the kilns it is removed to the grinding and pulverizing mills, where the final process of reduction is effected, and the cement then becomes suitable for all the varied purposes to which it may be applied.

The system of manufacture thus briefly described is simple in character, and on due and intelligent watchfulness being exercised by the manufacturer satisfactory results are easily obtained. The process is necessarily a dilatory one, and considerable time must elapse before the raw material can be converted into a marketable commodity. Under ordinary circumstances, a period of from two to three months is required to make Portland cement. This difficulty has led some manufacturers to a consideration of the question of superseding the tedious operation of washing or mixing by that of the dry process. Hitherto all our attempts at improvement in that direction have not been attended with much success. Some progress has, however, been attained in Germany by the manufacture of Portland cement without the necessity of using large quantities of water for the mixture of the raw materials. Should this improvement be capable of adaptation in England, a considerable reduction in the price of the cement will necessarily follow.

By any system of cement manufacture the primary object is the thorough amalgamation, in the minutest form, of the raw materials, so as to realize to the fullest extent the maximum value of the combination in subsequent stages of the process. For even the most accurate proportions of chalk and clay will not accomplish the desired end unless the comminution of the various particles is perfect and complete. The wet system, as the English method may be called, aims at and indeed accomplishes the required desideratum in the simplest and least expensive manner. The dry, or German system, as it may be distinctly named, likewise succeeds in thoroughly amalgamating the raw materials (chalk and clay). While the application of the wet system is limited to the manipulation of chalk or soft calcareous earths, the dry system may embrace the manufacture of Portland cement wherever materials exist containing the required proportions of carbonate of lime and clay. Indeed, it may almost be considered as capable of unlimited or universal application, as there are but few localities deficient in the necessary quantities of these materials in one form or other.

An accurate compliance with the simple conditions as above described, invariably results in the production of a Portland cement possessing all the essential qualities desired by the engineer and architect. Much attention is now being pointedly directed to the question of a good Portland cement supply, and the necessary tests are of so searching a character as to preclude the possibility of any but the best cements being used where due vigilance is exercised by those entrusted with works of construction. The questionable reputation which has for so long a time been attached to Portland cement was due as much to the professional indifference of the engineer or architect as the carelessness of the manufacturer; the one, probably impressed with a belief in the insignificance of the subject itself, and the other careless of the character attained by his commodity, so long as it brought profit to himself. Fortunately, the insistance of the engineers entrusted with the great drainage and embankment works of the metropolis, upon being supplied with Portland cement of undeniable quality, has resulted in the institution of tests, rendering the supply of faulty cement absolutely impossible where due and necessary vigilance is exercised. Experience acquired in those works has established beyond cavil that the most desirable cement is that which reaches or exceeds the following standard:—

1st. In weight not less than 110 lbs. an imperial bushel.

2nd. Exceeding fineness of powder, capable of being passed through a sieve of from 1600 to 3000 meshes to the square inch.

3rd. Equal to resist a tensile strain of 200 lbs. to the square inch, after being immersed for a period of seven days in water.

When these three conditions have been scrupulously complied with, there need be no hesitation in using Portland cement for any purpose of construction in water or the air.

Portland cement possesses in an eminent degree the valuable property of hydraulicity, or capacity of setting and hardening under water; and its many applications in the construction of harbours, docks, and breakwaters, have long since established its reputation for such purposes. It is now (1870) upwards of forty years since its first introduction, and during that period of time foreign engineers especially have devoted much attention to its properties and uses. Its appreciation in this country has not been so marked; but an awakening interest in the construction of concrete buildings is gradually leading to the question of its quality and supply.

When Portland cement is carefully and accurately manufactured, it should, on setting, be of a light grey colour, resembling Portland stone in appearance; and very probably this peculiarity had some influence on giving it the name it now bears. Any departure from this colour indicates a faulty cement, and proves that either the proportions of the materials are irregular, or that its decarbonization was incomplete. It does not deteriorate by exposure to the air, and may be stored even for years if kept in a dry place. Various proportions of sand may be mixed with it for mortar; sometimes as much as 8 parts of sand to 1 part of cement may be used if the cement is good in quality. Such a proportion, however, is not generally recommended; but one of 3 parts of sand to 1 part of cement will be found a good mixture for general building purposes. The cement when required for architectural embellishment should be worked neat, and for this purpose a quick-setting quality should be employed. The plasterer should, before using it, make a sample test in the shape of a small brick, or circular pats, which must be put in water as soon as possible after it is worked up by the trowel. If after twenty-four hours' immersion there are no faulty indications developed in the shape of cracks, the cement may be used with safety. For concrete purposes, the proportions are sometimes 1 part of cement to 8 parts of shingle or gravel. Large concrete-blocks, weighing 330 tons, have been successfully made near Dublin with proportions of 1 part of cement to 6 parts of Liffey gravel. This is probably the most striking example of the application of concrete in engineering work.

Recent experiments have proved that Portland cement continues to harden or crystallize for a lengthened period. Briquettes made of neat cement (weighing 121 lbs. a bushel), after seven days' immersion in water, bore a tensile strain of nearly 400 lbs. to the square inch; and duplicate briquettes, after five months' similar treatment, sustained a weight of nearly 600 lbs. to the square inch, showing thereby an improvement of 50 per cent. in that time. Further experiments with cement bricks, to prove their capacity of resistance to compression, resulted as follows.

Bricks three months' old, $9'' + 4\frac{1}{4}'' \times 2\frac{3}{4}''$ resisted fracture until a pressure of 65 tons was exerted by the agency of the hydraulic press. The weight was applied to the brick on its bed, having a surface of $38\frac{1}{4}$ sq. in. Similar bricks, under like conditions, at six months old, withstood a pressure of 92 tons. The third experiment, with a brick nine months old, resulted in 102 tons, showing upwards of 50 per cent. improved resistive value in a period of six months.

In the same series of experiments other building materials of acknowledged excellence were operated upon, and the following values were obtained:—

| | Exposed Surface. | Average Crushing Weight. |
|---|---|---|
| Oldham red bricks | 39·33 sq. in. | 40 tons. |
| Medway gault clay bricks | 40·50 „ | 17 „ |
| „ pressed „ | 40·50 „ | 48 „ |
| Stafford blue brick | 27·90 „ | 50 „ |
| Fireclay „ | 34·85 „ | 65 „ |
| Wortley blue „ | 34·76 „ | 72 „ |
| Portland stone | 39·94 „ | 47 „ |
| Bromley Fall stone | 39·94 „ | 91 „ |
| Yorkshire Landing | 38·28 „ | 96 „ |

Showing thereby that at nine months old a neat Portland cement brick exceeded in resistive value the best-known building materials of this country. It is quite possible also that a greater age may yet indicate an increase of strength, an advantage our experience does not lead us to expect from bricks or stones. Induration continues in the case of Portland cement to an extent beyond the limits of our present knowledge.

In another series of experiments it was found that cement, weighing 106 lbs. a bushel, resisted a tensile strain of 210 lbs. to the square inch, and when the weight of the cement was 130 lbs. a bushel it required an exertion of 406 lbs. an inch to cause rupture—showing that by an increase in weight of 24 lbs. a bushel the strength of the cement was nearly doubled.

Heavy cement is necessarily slow-setting in character; but these experiments and the most eminent engineering practice indisputably prove that without weight you cannot obtain great strength

The analysis of a good average sample of Portland cement should be—

| | | | |
|---|---|---|---|
| Calcium | 62 | Alumina | 8 |
| Silica | 23 | Oxide of iron | 4 |

To give full effect to the required conditions necessary to obtain a good Portland cement for building purposes, the use of a testing machine is indispensable; and on works of ordinary extent the engineer or architect should insist on its being applied to every delivery of cement sent on to the works.

About ten years ago, and indeed since then, many attempts have been made to introduce what were ostentatiously termed natural Portland cements, obtained from the blue lias lime formation of the West of England. Their indiscriminate use led to much dissatisfaction and loss, from their unfitness as a substitute for Portland cement, properly so called. The charm of cheapness for a time obtained for them a place amongst cements, and the comparative ignorance which then prevailed as to the essential qualities of a good cement enabled the manufacturers of these lias limes to hold a position in the market which a more advanced knowledge of the subject would now prevent.

The Boulogne-sur-Mer natural Portland cement differs considerably from the above, being made from a deposit of argillo-calcareous earth containing from 19 to 25 per cent. of clay; the silica and alumina of which is variable. When more than one-twentieth of sand is present in its composition it has to be rejected as unsuitable. This clay or earth is found in the inferior cretaceous formation.

The objection to all kinds of natural cements is the uncertainty in the value of their constituent parts. Their ever-varying ingredients render them unsuitable for building purposes when any degree of excellence or strength is required. No such obstacle exists in the use of sound Portland cement, and that is the reason why it lays claim to and maintains its superiority over all other kinds of cements. The manufacturers can, when duly impressed with the necessity of accuracy in manipulating the materials from which the cement is made, unerringly ensure the required results in quality and strength; the moderate limitation of which is only controlled by the cost.

In the above remarks it is not intended to convey the impression that there is any difficulty in making Portland cement of light specific gravity and colour. Portland cement can be made from 90 to 140 lbs. weight a bushel; but the value of the one is of course much less than the other; so also is its strength and quality—the light cement setting more speedily than the heavy cement. The colour also varies from a light buff to the deepest grey.

Notwithstanding the point of excellence to which Portland cement has attained, especially under the accurate and intelligent manipulation of Henry Reid, there is still much room for improvement in its manufacture. Its continually increasing application for all kinds and forms of construction points it out as a valuable agent for substituting concrete houses for the worthless brick buildings of this country. It is to be hoped that changes in the processes of manufacture will eventually result in reducing the price of an article which at present bears a very disproportionate relation to the value of the simple and inexpensive materials from which it is prepared.

*Roman Cement.*—This cement, although gradually giving way to its more energetic rival Portland cement, possesses nevertheless many good qualities. It differs from Portland, being a natural cement; and in consequence of there being great varieties of stones from which it is made, much care is necessary in ascertaining their exact quality before using it for building purposes. The origin of the name arose probably from its resemblance in colour and general characteristics to the mortar found in Roman remains in England. It was first introduced by Parker in 1796, who obtained a patent for manufacturing cement—named by him Roman—from the septaria nodules of the London clay found along the shores of the Isle of Sheppy, in Kent. Subsequently, Frost and other makers introduced Roman cement made from similar materials found in the clay formations of other districts in England. The term Roman is now generally applied to all natural cements of a dark brownish colour, and it is this distinguishing peculiarity which so markedly separates it from the Portland cement, which is of a grey colour. The Roman cement stone is found in many parts of England, North Wales, the Isle of Wight, and in Scotland. Several districts in France also furnish considerable quantities both from the clay and argillaceous limestone formations. There are very extensive deposits in the United States of America, from which is manufactured a cement resembling that of this country both in colour and other peculiarities. There can be no doubt that in many districts of England and Scotland this cement stone abounds; and it is only by reason of the apathy and indifference of engineers and architects on the subject that so little progress has been made towards its greater development.

The Roman cements generally sold in London are the Harwich, Isle of Sheppy, Southend, Isle of Wight, and Medina; in the North of England, the Yorkshire, Atkinson, or Mulgrave; in Liverpool, the Holywell, Flintshire, North Wales; and in Scotland, the Calderwood. In America it is extensively made in the states of Illinois, Ohio, Maryland, Virginia, and New York. Some years ago large quantities of these American cements were shipped to Australia and other places, and called Portland cements; but they differed so much from that article that their manufacturers finally abandoned their pretensions, after great loss had been incurred by the merchants who had shipped them.

In general, these cement stones contain about 60 per cent. of carbonate of lime, or magnesia, with from 30 to 40 per cent. of clay. The oxides of iron and magnesia which they contain are variable. Few of them have alumina or soda, and it is doubtless from the absence of these ingredients that they are so inferior to the artificial Portland. The clay is highly ferruginous in character, which to a great extent accounts for the rapidity with which they set; and to this cause also may be due their want of permanently indurative capacity.

The following analysis of well-known Roman cement stones will better explain the relative quantities of the ingredients:—

| | Clay. | Carbonate of Lime. |
|---|---|---|
| Parker's cement .. .. | 45·0 | .. .. 55·0 |
| Yorkshire „ .. .. | 34·0 | .. .. 62·0 |
| Sheppy „ .. .. | 32·0 | .. .. 66·0 |
| Harwich „ .. .. | 47·0 | .. .. 49·0 |

| | Oxide of Iron. | Silica. | Alumina. | Carb. Lime. | Mag. |
|---|---|---|---|---|---|
| Southend cement .. .. | 9·0 | 12·0 | 3·4 | 64·0 | 1·5 |

| | Protoxide of Iron. | Silica. | Alumina. | Carb. Lime. | Mag. |
|---|---|---|---|---|---|
| Calderwood „ .. .. | 10·2 | 8·8 | 3·4 | 64 | 2·6 |

The American cement stones have more alumina and less carbonate of lime than those of this country. It is a curious circumstance that, notwithstanding their excellence and abundance, Roman cement is still sent from London to New York.

A remarkable difference between the Roman and Portland cement is the necessity for applying opposite tests in selecting the best sorts when manufactured. Portland is best when heaviest: up to 140 lbs. weight a bushel if possible. On the other hand, Roman is judged by its lightness; and when it weighs about 75 lbs. a bushel it is best. These two different properties tell, however, in a most marked manner when we come to consider which is the better cement to keep for a lengthened period without deterioration. Portland cement possesses this valuable property in a high degree, and Roman cement can lay but little claim to this excellent quality.

The stone principally used in London is that obtained from the coast near Harwich, and is delivered in London by barges at a cost, according to quality, of from 6*s.* to 8*s.* a ton.

The process of manufacture is most simple, and the only care required is to prevent its being vitrified when burnt. The great aim is to have the cements of the lowest weight; this can only be attained by a maximum amount of decarbonization in the kiln. The stones lose in weight by this process about 30 per cent. without any appreciable loss in bulk. The form of kiln used does not differ much from the commonest kind of lime-kiln. It is usually from 20 to 25 ft. high, from 9 to 12 ft. wide at top, and from 7 to 8 ft. wide at the bottom. Each kiln has four eyes, or drawing-holes, to take away the stone when burnt; it is seldom necessary to have them all in use at the same time. The stone is broken to a uniform size of from 2 to 3 in., and placed in the kilns in layers; each layer having the necessary amount of fine coal placed on it, for the purpose of decarbonizing or burning the stone. The fuel required for this purpose varies, as the stone or coal is seldom regular in quality. The experienced burner will easily regulate the necessary quantity. When a kiln is once lighted up, it may be kept burning for many months without any attention beyond the regular daily withdrawal of the burnt stone and the addition of the fresh materials so that the kiln may always be kept full. The best and most profitable kiln is one with a 70 or 80 tons capacity. Smaller kilns, however, may be used in localities where the demand for cement is limited. It is advisable to adjust the size of the kiln so that it may always be burning; such an arrangement is the most economical, as you thereby save the waste incurred in relighting after each charge has been drawn. The burnt stone may be kept for a considerable time before being ground, and it is better, therefore, if necessary, to allow it to remain in this state than to keep the powder, as in that condition it speedily and permanently deteriorates.

The grinding or pulverization of the cement should be carefully attended to. The point of reduction is seldom, in this country at least, carried beyond the No. 30 gauge; but in America the engineers insist on having it ground so that only 8 per cent. will be rejected by an 80-gauge sieve (6000 meshes to the square inch). English engineers and architects have not been so exacting in their stipulations for fine grinding, and a No. 40 (1600) gauge may be considered as the maximum of pulverization of English Roman cement.

There can be no doubt that progress in the use of Portland cement was much retarded by interested Roman cement manufacturers, in consequence of the ease with which the latter could be made. Indeed, it was and is so simple in character that the most ignorant are almost capable of preparing it for the market. The selection of the stone itself is not difficult; and when the most ordinary care was bestowed on the processes of burning and grinding, the makers run but little risk in carrying on what doubtless was, until very lately, a very profitable trade. Roman cement can be prepared for the market in a few days. That advantage, from a manufacturer's point of view at least, was considerable; whereas the conversion of the raw materials into Portland cement occupied a period exceeding two months, according to the seasons. Again, the manufacture of Roman cement requires but little, if any, scientific or advanced technical knowledge. On the other hand, Portland cement making is attended with much risk and anxiety, and cannot be successfully conducted without a perfect knowledge of the raw materials and their accurate manipulation. For these cogent reasons, therefore, the ascendency of Roman cement was maintained for a much longer time than its merits really deserved. It was not until the professional mind was thoroughly awakened to its shortcomings and failings that it was, in important works at least, superseded by Portland cement, with good reason, as the following tests will prove.

It should be premised, to account for the variability of the results in the following Tables, that Roman cement, as already observed, is prejudicially influenced when in contact with the air and the moisture which it contains. Its highest value, therefore, can only be realized when fresh burnt and finely ground. The cement submitted to experiments was obtained from four makers of established reputation.

| | Age of Bricks. Tensile Strain per sq. in. in lbs. | | | |
|---|---|---|---|---|
| | 7 Days. | 1 Month. | 6 Months. | 1 Year. |
| No. 1 Maker .. .. .. .. | 89 .. | 108 .. | 167 .. | 144 |
| „ 2 „ .. .. .. .. | 89 .. | 116 .. | 209 .. | 286 |
| „ 3 „ .. .. .. .. | 54 .. | 160 .. | 112 .. | 120 |
| „ 4 „ .. .. .. .. | 60 .. | 96 .. | 194 .. | 212 |
| Medina .. .. .. .. .. | 41 .. | 136 .. | 183 .. | 212 |

Attempts were made during the time these experiments were being tried to extend their usefulness by ascertaining the value of the cement when mixed with various proportions of sand. The results, however, were found to be so low and unsatisfactory that the further search for information in that direction was abandoned, as not being likely to lead to any useful result.

Notwithstanding the many disadvantages attending the use of Roman cement, it must be borne in mind that it is to be found in many countries and localities where it might be readily used with advantage when Portland cement or hydraulic limes could not be obtained. It is now fre-

quently used in protecting the joints of Portland cement, while setting, from the injurious action of the sea or running water in harbour and similar works. Smeaton, when building the Eddystone Lighthouse, long before the introduction of Roman cement, used plaster of Paris, in protecting the joints of his composite mortar, made from puzzolana and blue lias lime, from the violent action of the sea.

Roman cement cannot bear a greater admixture of sand than 1 to 1. For concrete, however, in foundations at least, it may be used up to 5 or 6 of gravel to 1 of cement. In the Thames Tunnel neat cement was used for the arches, 1 of sand to 1 of cement for the foundations, and ½ sand to 1 of cement for the piers. When used for internal plastering, it requires painting to hide the unsightly reticulated appearance of its surface after having been exposed for some time to atmospheric action. Much unsightly plastering is executed in London, from a supposed economical application of Roman and Portland cements. The wall to be plastered is first coated with a layer of Roman cement, which, when dried, is covered with a thin coating of Portland to give a finish and appearance to the whole. This mode of using the two cements is highly objectionable, and can only proceed from a want of knowledge of the peculiarities of the cements, which differ so materially in their properties. It is difficult to put two layers of the same cement on each other. The joints between two coats of cement are seldom perfect.

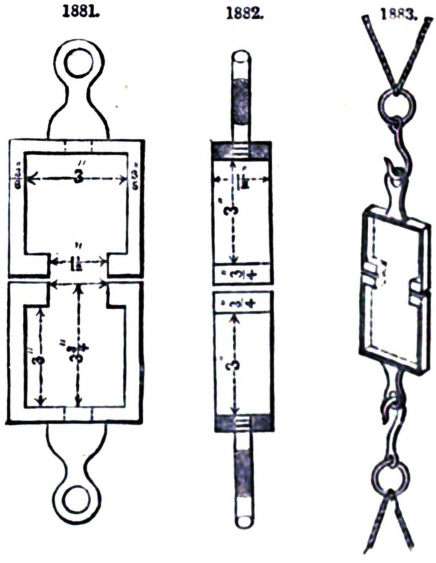
Cement manufacturing is an important branch of our industry. Some years ago, and before Portland cement had established its position, the English Government had their attention called to the scarcity of Harwich cement stone caused by its being dredged and taken away in large quantities by foreigners. The matter appeared of sufficient importance to attract the consideration of the late Sir Robert Peel, who intended levying a tax on the stone taken out of the country. On representation being made to him, however, that this country contained inexhaustible beds of raw materials which, when operated upon, produced an artificial cement much superior to the Roman, he abandoned his intended taxation.

It is remarkable that the three perhaps most celebrated engineering works of modern times led to improvements in mortars and cements. Smeaton, while (1756) experimenting on mortars for the Eddystone Lighthouse, discovered the value of puzzolana in combination with blue lias lime in imparting great setting energy to the mixture. Indeed, at that time he established the value of clay in conjunction with the carbonate of lime, which more than eighty years afterwards led to the investigation which ultimately resulted in the discovery of Portland cement. The construction of the Menai Bridge by Telford set at rest all doubts as to the value of Aberthaw lime for hydraulic purposes. The Thames Tunnel, again, furnished conclusive evidence of the great value of Roman cement, which was almost entirely used in its construction by the Brunels.

*Portland Cement.—Particulars specified by the War Office, England.*—Portland cement is to be of the best quality, ground extremely fine, weighing not less than 100 lbs. a striked bushel (filled into a bushel measure as lightly as possible), and capable of maintaining a breaking weight of 450 lbs. seven days after being made into a mould of the form and dimensions given in Figs. 1881 to 1883; the specimen being immersed in water as soon as it has set, and so left during the interval of seven days.

Cement placed in the testing-mould, Fig. 1883, to be experimented upon, must be in good condition, and thoroughly mixed on a clean floor, and applied as soon as mixed.

The cement and sand have to be carefully measured in proper measures, which are kept for the purpose.




*Hydraulic Cements, natural and artificial.*—The term hydraulic *cement* is generally used in distinction to hydraulic *lime*. The former, containing a larger proportion of silica and alumina and a smaller proportion of carbonate of lime than the latter, does not slake, and sets generally in a few minutes even under water. Hydraulic limes, on the other hand, slake thoroughly and harden slowly under water. Some limestones exist which, when completely calcined, yield hydraulic lime; but when imperfectly calcined, yield cement. Other limestones, such as chalk, when imperfectly calcined, or too much calcined, yield fairly hydraulic limes; while, if they be calcined merely up to the point when all the carbonic acid is driven off, and no further, they yield a lime which never solidifies under water. Other limestones yield on calcination a result which can neither be termed lime nor cement, owing to its slaking very imperfectly, and not retaining the hardness which it quickly takes when first placed under water.

The natural hydraulic cement best known in England, of which we have spoken, is that which is most absurdly termed *Roman cement*, or, more sensibly, *Parker's cement*. The stone is found in the form of nodules in the island of Sheppy. The composition of these nodules is almost the same as that of the Boulogne pebbles, from which a similar cement is made. Before being burnt, the stone is of a fine close grain, of a rather pasty appearance; the surfaces of fractures being greasy to the touch. It sticks easily to the tongue: its dust, when scraped with the point of a knife, is a greyish white. During the calcination the stone loses about one-third of its weight,

and the colour becomes of a brown tinge, differing with the stones from which the cement is made. It becomes soft to the touch, and leaves upon the fingers a very fine dust; it sticks very decidedly to the tongue. When taken out of the kiln it absorbs water with much difficulty. It is usually burnt in conical kilns, and pulverized by the manufacturer, and then sold in well-closed casks. In Russia, America, India, and elsewhere, similar natural cements have been met with; but, as they are comparatively rare and expensive, much attention has been bestowed on finding or inventing a substitute for them. Carbonate of magnesia alone has been found to yield, on calcination, an excellent hydraulic cement. When mixed with 1½ times its bulk of sand, it makes a beautiful hard plaster or stucco.

Vicat was the first to point out the method of forming an artificial hydraulic cement by the mixture of lime and unburnt clay; and General Pasley afterwards, in a most elaborate series of experiments, proved that a hydraulic cement might be formed equal to the best obtained from natural sources

Pasley's experiments were made principally with chalk lime and the blue alluvial clay of the river Medway, near Chatham. The result he arrived at was, that a mixture of 4 parts by weight of pure chalk, perfectly dry, with 5·5 parts, also by weight, of alluvial clay, fresh from the Medway, or of 10 parts of the former with 13¾ of the latter, would produce the strongest artificial cement that could be made by any combination of these two ingredients.

From the experiments of Vicat and Pasley on making artificial cements, it would appear that the best mixture for making cement consists, before burning, of

| | | |
|---|---|---|
| Two ingredients of carbonate of lime .. .. .. .. .. .. | 50·5 × 2 = 101·0 | |
| One ingredient of clay, of which the probable composition is— | | |
| One equivalent of alumina .. .. .. .. .. .. .. .. | 51·4 | |
| Six ditto silica .. .. .. .. .. .. .. .. .. .. .. | 93·0 | = 144·4 |
| | | 245·4 |

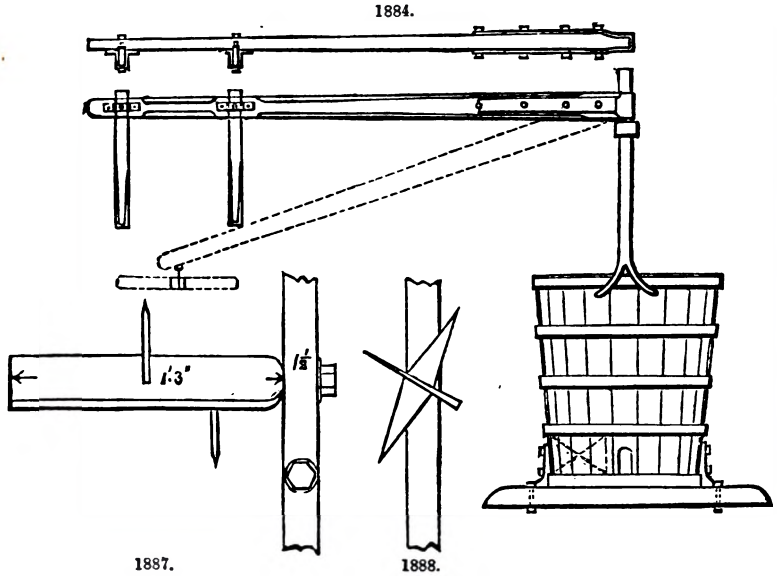
So that the composition in 100 parts is:—

| | |
|---|---|
| Carbonate of lime .. .. .. .. | 41 |
| Clay .. .. .. .. .. .. .. | 59 |
| | 100 |

The weight of the blue clay he found to be 90 lbs., and of the dry chalk powder 40 lbs. a cubic foot.

His method of proceeding was as follows:—The clay was weighed when fresh from the river (taken from about 18 in. below the surface), and was never dug unless required at once; it being found that even twenty-four hours' exposure to the atmosphere injured it. The chalk was not weighed until well dried and pounded, owing to its extraordinary retentiveness of moisture. The chalk was then mixed with water into a thick paste. The chalk and clay were then each separately divided into portions or lumps as nearly as possible equal, and put alternately into a pug mill of the ordinary description, Figs. 1884 to 1888, where they were most thoroughly and intimately mixed. The raw cement thus formed was then made up into balls of about 2½ in. in diameter, and placed in the kiln alternately with about equal layers of fuel—a layer of fuel always being at the top and bottom. The fuel used was coke, in preference to coal; and, in the small furnace or kiln used by Pasley, three hours was found to be about the average time required for burning the cement. As the calcined cement was drawn from the bottom of the kiln, fresh

1884.

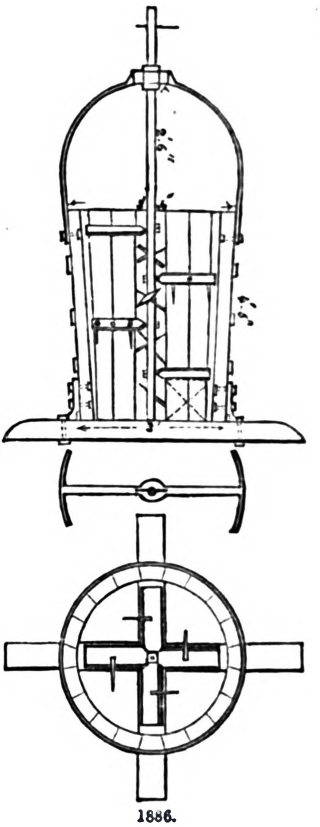



1887. 1888.

cement could be put in at the top. The balls, on being raked out, could be tested by applying to them diluted hydrochloric acid. If sufficiently burned, no effervescence ensued; but if they effervesced, they were put into the top of the kiln again to be reburnt. The calcined cement balls, since they would not slake like ordinary lime, were then ground to impalpable powder, and stored for use, so that they should not be exposed to the atmosphere. The average out-turn was about 9½ measures of calcined out of 10 measures of raw cement.

The proportions just named formed the best artificial cements. Pasley, after due investigation, found that any given weight of well-burned chalk lime, and consequently of any other pure quick-lime, fresh from the kiln, combined with *twice* its own weight of blue clay, fresh from the river, will form an excellent water cement; observing, however, that the quick-lime, after being weighed, must be slaked with excess of water into a thinnish paste, and allowed to remain in that state about twenty-four hours before it is mixed with the clay.

1885.



1886.

These proportions by weight are nearly equivalent to a mixture of 5 measures chalk powder to 2¼ measures of blue clay. Since 555 grains of quick-lime are the produce of 1000 grains dry chalk, which, in a state of powder, will fill 5 measures; of which 1110 grains of clay will fill 2¼ measures.

Portland cement is formed very much from the ingredients used by Pasley, but with different proportions. It takes its name from its likeness in colour to Portland stone; but it is in no way connected with it. The ingredients are chalk and the mud of the river Medway, in the neighbourhood of which it is chiefly manufactured. The process is as follows:—The chalk used contains about 7½ per cent. of clay. The mud contains about 70 per cent. of alumina and iron to 30 per cent. silica. Eight or nine parts of chalk with two parts of mud are passed through a crushing mill, into which is let a supply of water, which, running off at the side opposite that at which it enters, carries off the crushed particles into a large vat, 60′ × 40′ × 3′. Here the sediment settles down, and becomes tolerably solid, while the surface water is run off or evaporates. The mixture is now spread out on a drying floor to a depth of about 6 in., and is dried by coking ovens below it. These ovens, at the same time as they dry the raw cement, are converting coal into coke; and this being accomplished, both cement and coke are taken to the kiln, where they are spread in alternate layers, and burnt at a very high temperature. The cement, when burnt, is in a state of incipient vitrification: indeed, it should be over-burnt; as the particles should be just beginning to run together. This excessive burning is a distinctive feature of its manufacture. It is now crushed between two iron wheels revolving on one another, and ground between two sandstone millstones; and then the cement is complete, and is carefully packed in 3-bushel casks. The danger of the use of this cement is that it is apt to swell in the joints of masonry after being applied; but it is admirably adapted for buildings exposed to the action of water, and for external plastering, as it sets very fast and attains great hardness, and does not allow of the formation of vegetation, as the natural cements do.

*Coignet's agglomerated concrete* consists of a proportion of sand, a smaller quantity, perhaps ¼, of lime, and a minimum quantity of Portland cement, say $\frac{1}{15}$, $\frac{1}{10}$, or $\frac{1}{20}$. Instead of mixing these ingredients with mortar, so as to form a mortar of ordinary consistency, a very small quantity only of water is added, and the mass is made to undergo a trituration of greater or less duration by means of special apparatus. By this trituration, notwithstanding the feeble quantity of water, a pulverulent mass is obtained, which acquires by a more prolonged trituration the consistency of a firm plastic paste. It is then ready for the mould, into which it is introduced in successive and very thin layers, which are submitted to a powerful ramming process. This operation of compression effects such a complete agglomeration, that each cubic mètre and a-half of sand and lime is made to occupy the space of only 1 mètre; and the lime, whose particles are thus mechanically brought into contact, becomes indurated with astonishing rapidity and intensity. A few days, in some cases hours, suffice for the mass to acquire the character of hard stone.

As the work of one day, with this concrete, unites perfectly with that of the preceding, it is plain that a mass of this species of masonry can be augmented indefinitely, so that a house, bridge, reservoir, or any other construction, can be made to form a monolith.

The most important building executed in agglomerated concrete is the church of Vesinet, situated in a park of the same name, near Paris. It is of Gothic style, and the entire masonry forms a single block. The division of the naves is formed by piers of grouped colonnettes in cast iron; these, together with the cast-iron responds against the lateral walls, support the weight of the roof, which is of wrought iron. The concrete of which the walling is composed contains: river-sand, 3 parts; earthy and ferruginous sand, from Vesinet, 1 part; slacked lime, in powder, from Argenteuil, 1 part; heavy cement (*ciment lourde*), from Paris, ½ part; cement forming $\frac{1}{11}$ part of the whole.

Another advantage arising from the suppression of water, the energetic trituration, and the forced aggregation of the particles of lime, in these concretes, is, that a slight difference in quality

of the lime affects but little the result obtained; therefore the nearest hydraulic lime at hand will serve the purpose; whereas, in other concretes, the best lime must be obtained, in order to secure a good mortar. In fact, M. Coignet presented to the Society of Civil Engineers, in Paris, specimens capable of receiving a high polish, composed of the worst description of lime, even ordinary quicklime, bad and marly sands, fine sea-sand in impalpable powder unfit for common mortar.

With regard to the fact that, in masonry, mortars and concretes, when well made, are progressively and continually becoming harder, while cements do not acquire an increasing induration proportional to the energy of their original hardening or setting;—this may be explained by considering that cements contain very little free lime or oxide of calcium, being almost entirely composed of silicates formed by torrification at a high degree of temperature. Now, as pure lime has the property of absorbing, in order to pass into the state of carbonate, a quantity, nearly equal in weight to its own, of carbonic acid, it is plain that the more perfect a cement is—its perfection consisting in having but a trace of free lime—the less it will have the power of absorbing carbonic acid gas; whilst on the other hand the more a mortar contains of free lime, the more powerful and energetic will be the absorption, and the more the weight will be increased—that is to say, a cubic mètre of mortar containing 400 lbs. to 600 lbs. of free lime can absorb nearly 400 lbs. to 600 lbs. of carbonic acid, while a cement will absorb little or none.

This action of the carbonic acid of the air has a more striking effect upon agglomerated mortars and concretes than upon ordinary ones. It is easily understood that if to a compressed concrete like Coignet's, so dense that a cubic mètre contains 15 hectolitres of ingredients, with the particles so intimately blended by trituration, we add a new substance, carbonic acid, of equal weight with that of the pure lime, the increase of density of the whole mass will be great. Thus, the *bétons* agglomerated, composed of 5 parts of lime in powder, weighing 55 kilogrammes the hectolitre, and $\frac{1}{2}$ part or $\frac{1}{5}$ of cement, yield in a few days an artificial stone resisting more than 20 kilogrammes of crushing force per square centimètre; while substances, composed of 1 part of the best cement and 2 parts of sand, cannot withstand 10 kilogrammes of the same applied force. For lime mortars or concretes to harden into the state of artificial stone it requires much time.

Among the latest theories put forth by French engineers as to the cause of the setting of hydraulic cements, we may mention those laid before the Academy of Sciences, in Paris, by M. Fremy, last June. Vicat established that the hydraulicity of a cement is due to a composition formed when limestone is calcined in presence of argil. He states that this composition is a double silicate of alumina and lime, which, in hydrating, causes the setting of hydraulic cements. MM. Rivot and Chatonay, in their important work on Cements, state that the calcination of an argillaceous limestone produces aluminate of lime, the formula for which is $Al^2O^3$, 3 CaO, and also a silicate of lime, represented by $SiO^3$, CaO; these two salts, in contact with water, produce the two hydrates

$$Al^2O^3, 3\,CaO, 6\,HO, \qquad SiO^3, 3\,CaO, 6\,HO,$$

which become the cause of the hardening in question.

In both these two theories the hydraulicity of the cements is ascribed to a simple action of hydration, like the setting of plaster of Paris; but by M. Fremy another cause is assigned. He made extensive experimental researches on the properties and mutual action of four substances which, according to Vicat, Rivot, and Chatonay, constitute hydraulic cements:—1, silicate of lime; 2, silicate of alumina and lime; 3, aluminate of lime; 4, caustic lime, or oxide of calcium. The experiments are detailed in the memoir, which concludes with the following statement:—That the hardening of hydraulic cements is not due to the hydration of the silicate of lime, or that of the double silicate of alumina and lime; these salts *do not form any combination with the water:* that the setting of hydraulic cement is the result of two different chemical actions,—1, the hydration of the aluminates of lime; 2, the reaction of the hydrate of lime upon the silicate of lime, and upon the silicate of alumina and lime, which act in this case as puzzolana. The calcination of an argillaceous limestone cannot yield a good cement except when the proportions of argil and lime are such that these can be formed. In the first place, an aluminate of lime represented by one of these formulæ,—$Al^2O^3$, CaO; $Al^2O^3$, 2 CaO; $Al^2O^3$, 3 CaO: in the second place, a simple or multiple silicate of lime, represented approximately by one of these formulæ,—$SiO^3$, 2 CaO; $SiO^3$, 3 CaO; and in the third place, pure lime capable of acting on the preceding puzzolanic silicates.

In the course of the memoir, M. Fremy states that when aluminates of lime represented by $Al^2O^3$, CaO; $Al^2O^3$, 2 CaO; $Al^2O^3$, 3 CaO, are reduced to a fine powder, and slightly wetted, they solidify almost instantaneously, and produce hydrates which acquire in water a considerable degree of hardness. They have, moreover, the property of agglomerating inert substances, such as quartz, sand, and so on.

M. Fremy mixed aluminate $Al^2O^3$, 2 CaO, with 50, 60, and even 80 per cent. of sand, and obtained a pulverulent mass which in water acquired the hardness and solidity of the best stone. The interest attached to these mixtures of aluminates of lime and siliceous substances is the more important in a practical point of view when we consider that blocks are required to be produced capable of resisting atmospheric influences and the powerful effects of sea-water. M. Fremy considers that the solution of the problem of constructions resisting the ravages of the sea lies probably in the employment of concretes which are formed nearly wholly of siliceous substances united together by a feeble proportion of aluminate of lime. On this point M. Fremy cites the indications given by M. Coignet on the subject of agglomeration of cements, saying that he has observed their importance himself.

Portland cements, according to M. Fremy, have no good quality unless they are produced at a very high temperature. The aluminates of lime have this character, also, of not being able to solidify under water unless they have been exposed to an intense heat; thus they seem to be the principal agents in hydraulic cements of rapid setting.

Perhaps the inferiority of some of the Portland cements of commerce may be traced to want of sufficient intensity of heat in burning. M. Fremy made the aluminates of lime, for his experiments,

with a blast furnace. See ASPHALTE. CONCRETE MACHINE. FOUNDATIONS. KILNS. LIME AND MORTAR. OVENS.

*Recapitulation.—Roman Cement.—Parker's Analysis.*—One part of common clay to 2½ parts of chalk, set very quick.

*Concrete.*—Eight parts of pebble, or pieces of brick, about the size of an egg, to 4 parts of scrap river-sand, and 1 part of lime, mixed with water and grouted in, makes a good concrete.

*Lime Mortar.*—One part of river-sand to 2 parts of powdered lime mixed with fresh water.

*Hydraulic Mortar.*—One part of pounded brick powder to 2 parts of powdered lime mixed with fresh water. This mortar must be laid very thick between the bricks, and the latter well soaked in water before laid.

*Hydraulic Concrete, by Treussart.*—Thirty parts of hydraulic lime, measured in bulk before slaked; 30 parts of sand, 20 parts of gravel, and 40 parts broken stone—a hard lime-stone. This concrete diminishes about one-fifth in volume after manipulation.

*Asphalte Composition for Street Pavement, by Colonel Emy.*—2½ pints (wine measure) of pure mineral pitch, 11 lbs. of bitumen, 17 pints of powdered stonedust, wood-ashes, or minion.

*Cement for Stone and Brick Work.*—Two parts ashes, 3 of clay, and 1 of sand, when mixed with oil, will resist the weather equal to marble.

*Brown Mortar.*—One part lime, 2 of sand, and a small quantity of hair.

*Hydraulic Mortar.*—Three parts of lime, 4 puzzolana, 1 smithey ashes, 2 of sand, and 4 parts of rolled stone or shingle.

*Cements for Cast Iron.*—Two oz. sal-ammoniac, 1 oz. sulphur, and 16 oz. of borings or filings of cast iron, to be mixed well in a mortar, and kept dry. When required for use, take 1 part of this powder to 20 parts of clear iron borings or filings, mixed thoroughly in a mortar; make the mixture into a stiff paste with a little water, and then it is ready for use. A little fine grindstone sand improves the cement.

Or, 1 oz. of sal-ammoniac to 1 cwt. of iron borings. No heat allowed to it.

The cubic contents of the joint in inches, divided by five, is the weight of dry borings in pounds (avoirdupois) required to make cement to fill the joint nearly.

*Works on Cements:*—B. Higgins, 'On Calcareous Cements and Quick Lime,' 8vo, 1780. Treussart, 'Mémoire sur les Mortiers Hydrauliques,' 4to, Paris, 1829. L. J. Vicat, 'On Calcareous Mortars and Cements,' 8vo, 1837. Pasley, 'On Limes, Calcareous Cements, and Mortars,' 8vo, 1847. W. A. Becker, 'Pratische Anleitung zur anwendung der Cemente,' folio, Berlin, 1861–68. J. G. Austin, 'On Limes and Cements,' post 8vo, cloth, 1862. Gillmore (Q. A.), 'Practical Treatise on Limes, Cements, and Mortars,' 8vo, New York, 1864. Burnell, 'On Limes, Cements, and Mortars,' post 8vo, 1868. H. Reid, 'Practical Treatise on the Manufacture of Portland Cement,' 8vo, 1868. Dr. W. Michaelis, 'Die Hydraulischen Mörtel,' 8vo, Leipzig, 1869. R. D. Charleville, 'Traité sur l'Art de faire de bons Mortiers,' 8vo, Paris.

CENTRE-BIT. FR., *Mèche anglaise;* GER., *Centrumbohrer;* ITAL., *Saetta a centro;* SPAN., *Berbiquí.*

See AUGERS. HAND-TOOLS.

CENTRE OF GRAVITY. FR., *Centre de gravité;* GER., *Schwerpunct;* ITAL., *Centro di gravità.* SPAN., *Centro de gravedad.*

See GRAVITY. *Centre of Oscillation,* see OSCILLATION. *Centre of Percussion,* see PERCUSSION. *Centre of Gyration,* see ANGULAR MOTION, p. 103.

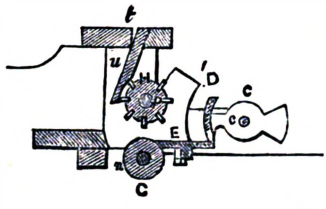
CENTRIFUGAL PUMP. FR., *Pompe à force centrifuge;* GER., *Centrifugalpumpe;* ITAL., *Tromba centrifuge;* SPAN., *Bomba centrífuga.*

See PUMPS.

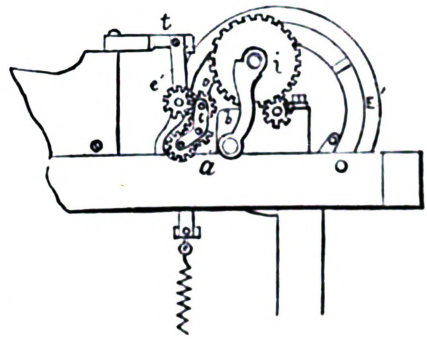
CHAFF-CUTTER. FR., *Coupe-paille, Hachoir;* GER., *Häckselladc;* ITAL., *Trinciapaglia;* SPAN., *Máquina para cortar paja, &c.*

The cutting device in F. B. Hunt's chaff or straw cutter, Figs. 1889 and 1890, deserves particular attention. The machine in which this device is employed consists of a spirally-arranged

1890.




1889.




knife secured to two arms upon a shaft in front of a feed-box, so that as the shaft is rotated the knife works closely over the outer edge of a metallic bed-plate attached to the feed-box. The upper roller is so arranged as to adjust itself to the varying thickness of the layer of straw or other substance pressed under it, the roller raising or falling in the arc of a circle, so as to be always at the same distance from the shaft of the cutter, and the substance to be cut will be retained in a proper position on the bed of the machine. Attached to the frame of the upper feed-roller is a guard-board or plate, which is caused to rise or fall with the upper feed-roller, so as to prevent the substance being cut from passing over the top of the roller.

In referring to Figs. 1889, 1890, it will be observed that the combination, of the cutting-bar or plate E of the single knife D and the arms *c, c,* attached to the driving-shaft C, operate to effect an

oblique or drawing cut. The fly-wheel E′ is so attached to its shaft C that the wheel is admitted to slip on the shaft in case the motion of the cutter is arrested by any foreign substance, thus the knife or cutter is preserved. The bar *c b* is connected directly to the shaft *n*, shown in section, Fig. 1890; *n* is the shaft of the lower feed-roller G, which is connected to the shaft *p* of the upper feed-roller H by an arm *s*. The bar *c b*, Fig. 1889, has pinions *b d* attached to it, which gear with the pinions *a′ c′* of the feed-roller shafts *n*, *p*, exhibited in section, Fig. 1890. The guide-board or guide-plate *u* is attached to the plate *t* of the frame of the upper feed-roller H; *u* extends down at the back of H to a level with *p* the shaft of H.

CHAIN PUMP. Fr., *Pompe à chapelet;* Ger., *Kettenpumpe;* Ital., *Noria;* Span., *Bomba de cadena.*

See Pumps.

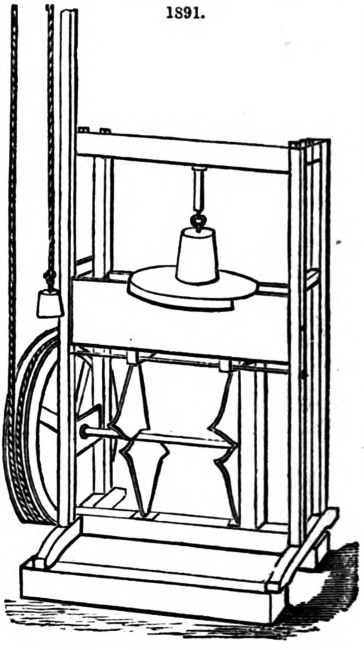
CHECK-VALVE. Fr., *Soupape d'arrêt;* Ger., *Absperrventil.*

See Valves.

CHEESE PRESS. Fr., *Machine à comprimer le fromage;* Ger., *Käsepresse;* Ital., *Torchio da formaggio;* Span., *Prensa de queso.*

*Dick's Anti-friction Cheese Press.*—In Fig. 1891 is represented the method of applying Dick's anti-friction power to the pressing of cheese. By the use of this press the whey is entirely removed, and half the labour usually required in the manufacture of cheese is saved, it being ready for market or transportation as it comes from the press, without risk or loss to the purchaser and the consequent vexation so frequent in the case of the method originally pursued. The pressing may be carried to any extent deemed requisite without danger to the press, the working portions of the press being made of iron, and capable of sustaining the force that may be applied.

1891.



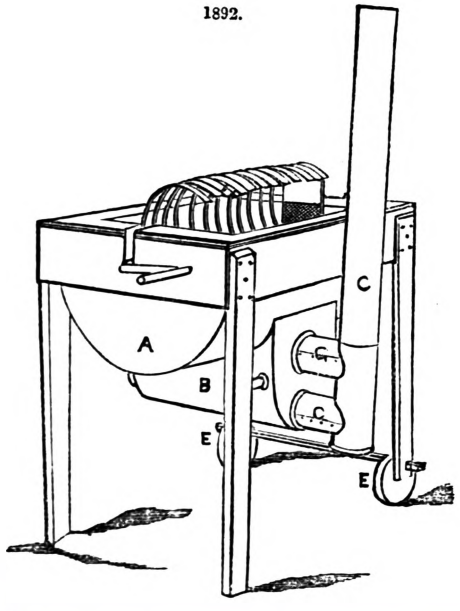
Attached to this press is the platform-scale; so that the cheese can be accurately weighed before it is removed from the press—a matter of great convenience and importance to the manufacturer and vendor of these articles, as well as to the purchaser, who can depend upon the weight marked upon it as strictly accurate. In fact, the advantages of this press, above others, must be at first view apparent, and the power such that it will come into general use.

CHEESE VAT. Fr., *Eclisse à fromage;* Ger., *Käsenapf;* Ital., *Tino da formaggio;* Span., *Quesera.*

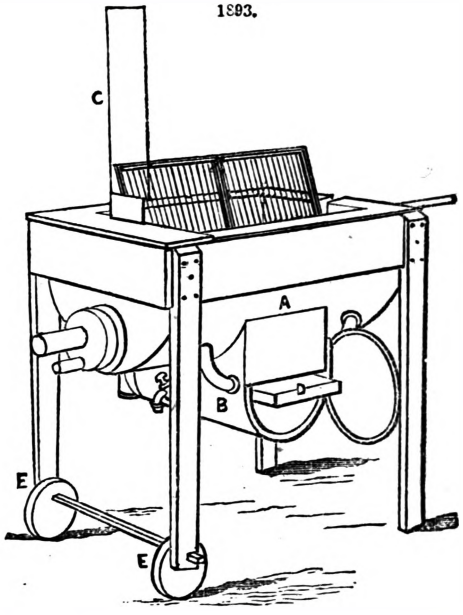
The objects to be attained by the use of a cheese vat are: a separation of the caseous or cheesy particles from the whey or watery particles of the milk, and the proper comminution of the latter preparatory to pressing. P. Colvin's cheese vat, Figs. 1892 to 1895, is intended to produce these results effectually, rapidly, and economically.

Fig. 1892 is a front view of the machine in perspective; Fig. 1893, an end view; Fig. 1894, a stirring-frame; and Fig. 1895, a cutting-frame; both these last operated by a crank. The vat A is semi-cylindrical and double-walled,

1892.




1893.

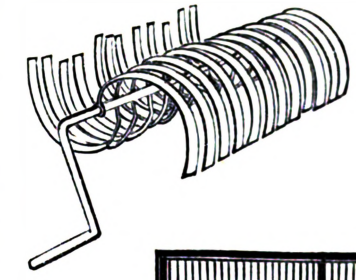


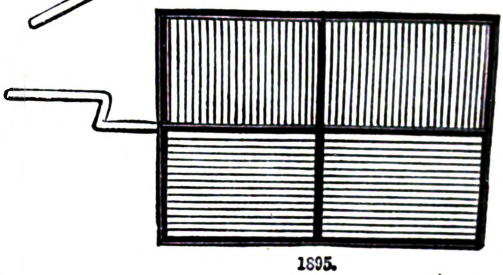

water being contained between the shells. Under the vat, and attached thereto, is a furnace B for heating the water, the smoke from which escapes by the pipes C.

The degree of heat admitted to the water is regulated by a sliding damper D, Fig. 1893. A coil of circulating pipes is affixed to the outer shell of the vat, connected with the water-space at the centre and ends of the vat, thus equalizing the heat in the water-space. Convenient spouts or cocks are attached for drawing off the whey, the water from the water-space, and discharging the curd.

To aid in this, one end of the machine is set on eccentrics E. For keeping the curd separate during the operations of scalding, salting, and cooling, a stirring-frame, Fig. 1894, turned by a crank, is used. This stirring-frame consists of curved paddles, and does the work usually performed by hand with a paddle; it is seen placed in the vat in Fig. 1892. The cutting-frame, Fig. 1895, seen in place in the machine, Fig. 1893, cuts the curds into small blocks by the longitudinal and transverse cutters on the rotating frame. This not only cuts the curd, but by its sweep cleans it from the inner surface of the vat. Either of these revolving frames may be lifted instantaneously from the vat, as the shafts bear at one end on a fixed pin, and at the other rest in an open box. At the discharge end of the vat, Fig. 1893, is a semicircular recess separated from the vat proper by a strainer-plate sliding in vertical grooves in the inner shell of the vat, and can be withdrawn vertically when the curd is to be discharged into the hoop of the press.

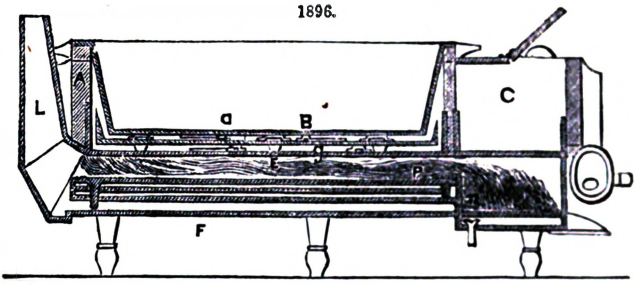
1894.





1895.

1896.




W. Ralph's cheese vat, Fig. 1896, has a false bottom D, so constructed that the water heated by the furnace E does not come in contact with the bottom of the inner vat B until the water has been in contact with the ends and sides of the vat and imparted a portion of its heat to the same. Hollow pipes F, arranged with a valve *n* and damper P, extend from the false bottom to the heated water below, and open at the top under hollow supports *g* upon which the vat rests.

CHEVAUX DE FRISE. Fr., *Chevaux de frise;* Ger., *Spanische oder friesische Reiter;* Ital., *Cavalletto di frisa;* Span., *Caballo de frisa.*

See Fortification.

CHIMNEY. Fr., *Cheminée;* Ger., *Schornstein;* Ital., *Camino;* Span., *Chimenea.*

The appellation *Chimney Stalk* is usually applied to a lofty chimney; such stalks are erected for steam-engines, or employed to create a draught of air through furnaces.

1. Heating apparatus vary in form and arrangement with the nature of the effect to be produced, but in general they all consist of three distinct parts: the furnace or place in which the heat is generated, the place in which the heat is utilized, and the chimney.

The function of chimneys is twofold:—

1st. To discharge at a great height in the atmosphere, the heated air often charged with smoke, which would be noisome to animal life if ejected at a small altitude.

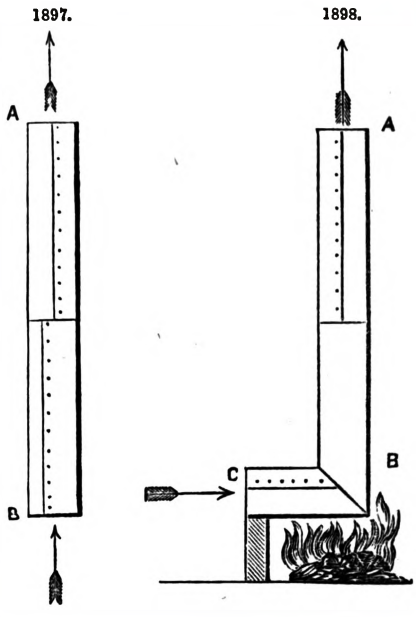
2nd. To cause a sufficient flow of air through the furnace to maintain combustion.

2. *Motion of Heated Air in Vertical Tubes.*—When a mass of air is at a temperature above that of the surrounding air, it has a tendency to rise in virtue of a force equal to the excess of the weight of the air displaced over its own weight. This is a particular case of the principle of Archimedes.

The same thing happens when the heated air is contained in a vertical tube A B, Fig. 1897, open at both ends. If we represent by P the pressure of the atmosphere in kilogrammes at the height of the point A, upon a surface equal to the section of the tube, and by $p$ and $p'$, the weight of two columns of air having the volume of the tube under the atmospheric pressure, one at the temperature of the external air, the other at that of the heated air, it is evident that the pressure at the point B, exerted in an upward direction, will be $P + p$, and that the pressure at the same point, exerted in the contrary direction, will be $P + p'$. Therefore the column of heated air will have a tendency to rise in virtue of the pressure $p - p'$. It follows from this, that if the pipe A B be fixed at the bottom to a horizontal pipe B C, heated externally, Fig. 1898, the external air will enter constantly through the orifice C, and will escape through the orifice A. This flow of air takes place in virtue of the excess of the atmospheric pressure at the point C over the internal pressure at the bottom of the pipe A B.

3. To determine the velocity of ingress of the external air at the point C, supposing the section

of the tube constant, we must remember that the flow of a liquid or of a gas, the resistance depending on the form and the dimensions of the tube apart, is represented, from the point of view of velocity, by the formula $v = \sqrt{2gP}$, in which P denotes the height of a column of fluid subjected to the pressure, and which would hold this pressure in equilibrio, however it might be produced. In the case in question, P is evidently the height of a column of external air, and its value is readily found.




Denoting the height of the chimney from the centre of the section C, Fig. 1898, by H, the external temperature by $\theta$, that of the air inside the chimney by $t$, and the pressure of the atmosphere at the point A, in air at $\theta°$, by M, the pressure of the point C, from the outside inwards, measured by a column of air at $\theta°$, will be M + H, and the pressure in the contrary direction, measured in the same way, will be

$$M + H\,(1 + a\,\theta) \div (1 + a\,t).$$

Consequently, we shall have as the excess of the former pressure over the latter,

$$M + H - \left(M + \frac{H(1 + a\,\theta)}{1 + a\,t}\right) = \frac{H\,a\,(t - \theta)}{1 + a\,t};$$

and therefore,

$$v = \sqrt{\frac{2\,g\,H\,a\,(t - \theta)}{1 + a\,t}}. \qquad [A]$$

4. It may be useful to remark that the pressure at any height in the column of heated air is equal to that at the point C. If we consider a horizontal section of the chimney at a height H′ from the top, the upward pressure which it will support, reckoned in air at $\theta$, will be $M + H - (H - H')\frac{1 + a\,\theta}{1 + a\,t}$; the pressure in the contrary direction will be $M + H'\frac{1 + a\,\theta}{1 + a\,t}$; and subtracting one from the other we find, as before, $H\,a\,\frac{(t - \theta)}{1 + a\,t}$.

5. For the rate of flow of the hot air, as the velocities are in inverse proportion to the densities, we shall have

$$v' = v\,\frac{1 + a\,t}{1 + a\,\theta}; \text{ whence } v' = \sqrt{\frac{2\,g\,H\,a\,(t - \theta)\,(1 + a\,t)}{(1 + a\,\theta)^2}}. \qquad [B]$$

6. The formulæ [A] and [B] may be put into a more convenient form for practice, by substituting for the term $\sqrt{2\,g\,a}$ its value; we shall then have

$$v = 0{\cdot}268\,\sqrt{\frac{H\,(t - \theta)}{1 + a\,t}}; \text{ and } v' = \frac{0{\cdot}268}{1 + a\,\theta}\sqrt{H\,(t - \theta)\,(1 + a\,t)}.$$

The formula [A] is alone important, for the useful effect of chimneys always consists in their ability to create a draught.

7. We have supposed that the density of the air depended only upon its temperature. This is not strictly true, for the density of the air at the same temperature decreases with the increase of altitude; but it is obvious that in the highest chimneys, the variations of density resulting from variations of height are quite imperceptible. For the altitude $0^m{\cdot}76$ of the barometer, the pressure of the atmosphere is represented by a column of water of $0^m{\cdot}76 \times 13{\cdot}6 = 10^m{\cdot}336$, and by a column of air at 0°, under the same pressure, equal to $10^m{\cdot}336 \div 0{\cdot}0013 = 7950^m$. Thus, the density of the air at a height of 20 mètres, for example, would be to that of the air at the surface of the earth in the ratio of 7930 to 7950, that is, in that of 1 to 1·0025, a variation of no importance whatever.

8. We have supposed the vertical tube cylindrical and completely open at the ends; but it is evident that the position and form of the pipe have no influence on the force produced by the ingress of external air, when the temperature of the pipe is everywhere equal to $t$, H representing the difference of level between the two ends of the column of heated air. If the air, in ascending the pipe, met with variations of temperature, we should have to take for $t$ the mean temperature.

9. The formula [A] gives the velocity or rate of ingress of the external air, all resistance apart; but there is always a loss of force attributable to friction and the form of the tube. If the chimney, instead of being cylindrical, varied in section and direction, the weight or force which would cause the inward flow of cold air would be still the same; but the actual rate of ingress would be found by taking into account the resistance, by means of the general formula given. We will return to this question later.

10. To determine how the rate of ingress V of the external air varies with the increase of $t$, according to the formula [A], suppose $\theta = 0$; this formula becomes $v = \sqrt{2\,g\,H}\sqrt{\frac{a\,t}{1 + a\,t}}$. The first factor of the value of $v$ represents the velocity acquired by a body falling from the height

H; and, as the second factor is always less than unity, the rate of ingress is never more than a fraction of this velocity. Taking successively for $t$ 50°, 100°, 150°, 200°, 250°, 300°, 350°, 400°, 500°, 1000°, 1500°, 2000°, we find as the values of the second factor, 0·39, 0·51, 0·57, 0·64, 0·68, 0·71, 0·74, 0·76, 0·80, 0·88, 0·91, 0·93. These numbers divided by the first, 0·39, give the ratios: 1, 1·31, 1·51, 1·65, 1·76, 1·83, 1·90, 1·96, 2·06, 2·25, 2·34, 2·38. Thus the rate of ingress of the cold air increases constantly with $t$, but this increase has a limit; for as $t$ increases, the ratio $\frac{at}{1+at}$, which is equal to $\frac{a}{\frac{1}{t}+a}$, constantly approaches unity, and consequently, the rate of ingress of the cold air, from $t = 50°$ to $t = \infty$, varies in the ratio of 0·39 to 1, or in that of 1 to 2·56.

It follows from this that the rate of ingress of the cold air increasing very slowly with the temperature, the useful effect of the chimney costs in fuel an amount proportionate to the temperature within the chimney.

The maximum rate of ingress of the outside air being $\sqrt{2gH}$, for chimneys of 5m, 10m, 20m, 30m, 40m, it is equal to 9m·9, 14m·0, 19m·8, 24m·3, 28m·0, and for an excess of temperature of 300°, the rate would be only 0·71 of the maximum. The velocity is besides considerably reduced by the resistance experienced by the heated air when in motion, as we shall see later.

11. We have supposed that the air, entering the vertical pipe, underwent, while being heated, no other change of density than that resulting from the change of temperature. But usually the heat is caused by combustion, the nature of the gas is changed, and it is necessary to see what the formulæ [A] and [B] become when the tabular density of the gas is equal to $\delta$, instead of being equal to unity.

In this case, the height of the inner column, reduced to $\theta°$, and to the density of the outer air, will be $\frac{H\delta(1+a\theta)}{1+at}$, and the difference of the two columns, or the force, will become

$$H - \frac{H\delta(1+a\theta)}{1+at} = \frac{H[1-\delta+a(t-\delta\theta)]}{1+at}; \text{ or, } \frac{H(1-\delta+at)}{1+at}$$

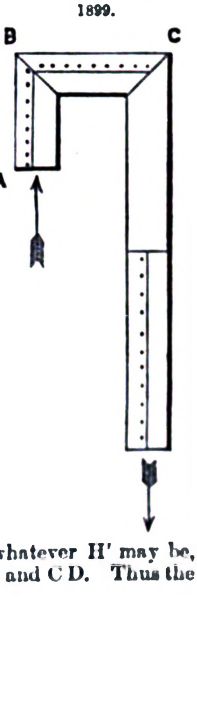
by rejecting the term $\delta a \theta$.

If, for example, the whole of the oxygen were transformed into carbonic acid, the density of this latter gas being 1·529, and that of ozote 0·976, the density of the mixture would be

$$0{\cdot}21 \times 1{\cdot}529 + 0{\cdot}79 \times 0{\cdot}976 = 1{\cdot}091;$$

if only half the oxygen were transformed into carbonic acid, which is the ordinary case, the density would be only 1·04. Neglecting $\theta$ in the expression of the force, it would become in the two cases, $\frac{H(at-0{\cdot}091)}{1+at}$; and $\frac{H(at-0{\cdot}04)}{1+at}$: and these would be the same if the values of $t$ were diminished by 25° in the first case, and by 11° in the second. These variations are of small importance, especially when $t$ is considerable. Besides, as the gases which are evolved in the furnaces always contain a certain quantity of steam obtained from the water held by the combustibles, and as the density of steam is equal to 0·621, its pressure diminishes the effect of the carbonic acid. Thus we may admit, as an approximation amply sufficient in practice, that the effect produced by a column composed of air and gases, resulting from combustion, is the same as if the column were of pure air.

12. *Motion of Heated Air in a Pipe consisting of several Vertical Tubes successively passed through.*— If the heated air traverses successively, ascending and descending, several vertical tubes in which the temperature is not the same, the force or pressure at the beginning of the pipe will depend at once on the heights of the tubes and the temperatures of the heated air. We will endeavour to determine it in a general manner.




13. Let us, in the first place, consider a chimney A B, Fig. 1899, extending horizontally in the direction B C, and descending again vertically in the direction C D, so as to form a syphon.

If we represent by $t$ and $t'$ the temperatures of the air in the portions A B and C D, by $\theta$ that of the external air, by $p$ and $p'$ the pressures of the atmosphere at the points A and D reckoned in air at $\theta°$, under the normal pressure, and by $m$ and $m'$ the heights of the columns of air at $\theta°$, equivalent to the columns of heated air A B and C D, the force in air at $\theta°$, which will produce the rush of cold air at the point A, will evidently be equal to $p - m + m' - p'$; and as the pressure of the external air at the point D exceeds that at the point A by a column of external air equal to H′ − H, we shall have as the force in air at $\theta°$, at the point A,

$$p - \frac{H(1+a\theta)}{1+at} + \frac{H'(1+a\theta)}{1+at'} - (p+H'-H) = \frac{Ha(t-\theta)}{1+at} - \frac{H'a(t'-\theta)}{1+at'}.$$

Thus the force is equal to the difference of the corresponding forces at the two branches supposed alone. The flow will evidently take place in the direction A B, as we had supposed, if the preceding expression be positive. Taking the external air at $\theta°$, and rejecting the terms $Ha^2tt'$ and $H'a^2tt'$, which are always small, seeing that $a^2 = 0{\cdot}000134$, the value of the force in external air becomes $\frac{a(Ht-H't')}{1+a(t+t')}$, an expression that is positive when $Ht$ is greater than $H't'$, a circumstance which may always be obtained, whatever H′ may be, by diminishing $t'$. This may be effected by cooling the air in the tubes B C and C D. Thus the

gases evolved in the furnace may always be discharged at any height, even beneath the level of the furnace.

14. If there were a third column E F, Fig. 1900, denoting its height by H'', and the mean temperature of the air in it by $t''$, by $m''$ the height of a column of air at $\theta^\circ$ producing the same pressure, and retaining the preceding notation, the force at the point A would be $p - m + m' - m'' - p'$; but we have $p' + H'' - H' + H = p$, and therefore the force at the point A in air at $\theta^\circ$ will be

$$p - \frac{H(1+a\theta)}{1+at} + \frac{H'(1+a\theta)}{1+at'} - \frac{H''(1+a\theta)}{1+at''} - p - (H'' - H' + H)$$

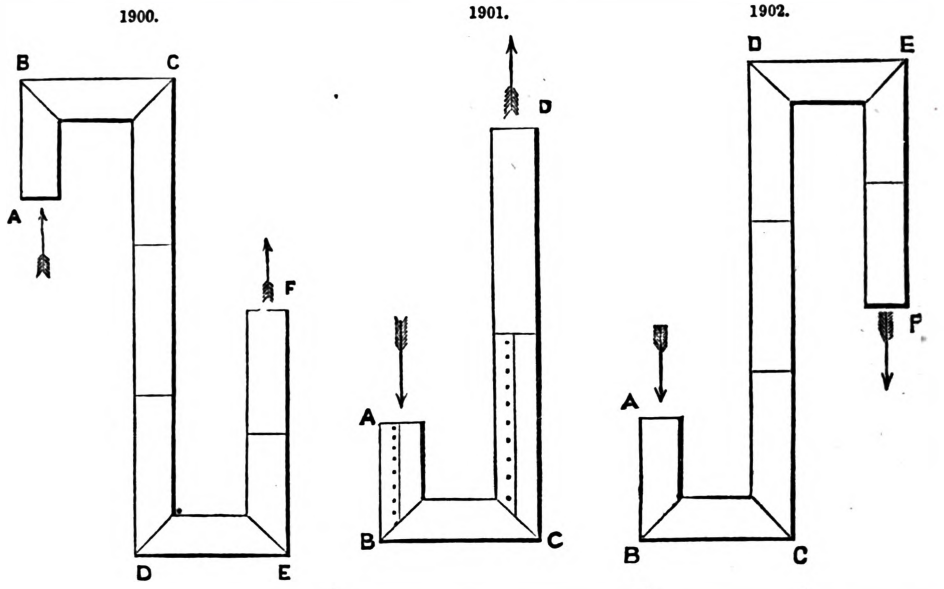
$$= \frac{H a (t-\theta)}{1+at} - \frac{H' a (t'-\theta)}{1+at'} + \frac{H'' a (t''-\theta)}{1+at''}.$$

The flow will take place in the direction A F, when this expression is positive. Rejecting, as before, the terms containing $a^2$, and *a fortiori* $a^3$, and supposing $\theta = 0$, the preceding expression is reduced to $\frac{a(Ht - H't' + H''t'')}{1+a(t+t'+t'')}$, an expression which will be positive when $Ht + H''t''$ is greater than $H't'$.

It would be easy from this to find the formula for any number of tubes.

15. Let us now suppose the pipe to have the form of a syphon reversed, Fig. 1901; retaining the same notation, the force at the point A, in air at $\theta^\circ$, will be $p + m - m' + p'$; or

$$p + \frac{H(1+a\theta)}{1+at} - \frac{H'(1+a\theta)}{1+at'} - p + H' - H = -\frac{Ha(t-\theta)}{1+at} + \frac{H'a(t'-\theta)}{1+at'}.$$




As in the preceding case, the effect produced is equal to the difference of the effects which the two branches would produce alone. Rejecting the terms containing $a^2$, and making $\theta = 0$, the value of the force is reduced to $-\frac{a(Ht - H't')}{1+a(t+t')}$, a value which will be positive when $H't'$ is greater than $Ht$; this condition may always be satisfied by increasing H', and by preventing the cooling of the air in the horizontal portion B C.

16. If the pipe were formed of three tubes, Fig. 1902, the force at the point A, in air at $0^\circ$, would evidently be $p + m - m' + m'' - p'$; or

$$p + \frac{H(1+a\theta)}{1+at} - \frac{H'(1+a\theta)}{1+at'} + \frac{H''(1+a\theta)}{1+at''} - (p + H - H' + H'')$$

$$= -\frac{Ha(t-\theta)}{1+at} + \frac{H'a(t'-\theta)}{1+at'} - \frac{H''a(t''-\theta)}{1+at''},$$

or on the hypothesis $\theta = 0^\circ$, $\frac{a(-Ht + H't' - H''t'')}{1+a(t+t'+t'')}$.

The force for any number of tubes may be readily calculated in the same way.

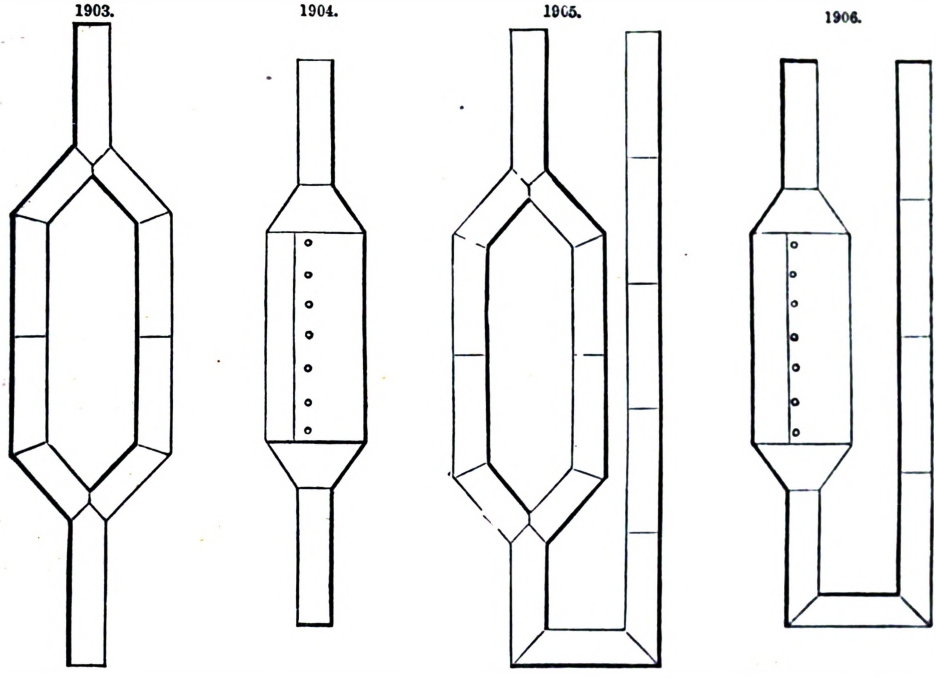
In general, the effect produced is equal to the sum of the effects produced separately by the tubes in which the heated air rises, diminished by the sum of the effects produced by the tubes in which the heated air descends.

17. It is of importance to remark that in the case in which the heated gas begins by descending, supposing the expression of the force to be positive, motion will not take place until the system of syphons has been put into action by heating some of the branches in which the air ascends. It is

evident that this precaution will not be needed in the case in which the heated air ascends in the first column.

18. *Motion of Heated Air in a Pipe consisting, throughout a certain length, of several Vertical Tubes traversed simultaneously.*—Let us consider, in the first place, a vertical pipe, Fig. 1903, consisting, throughout a certain length, of two equal and parallel branches. If both contain air at an equal temperature, everything else being equal in the two branches, the ascending heated air will traverse them with the same velocity; but however little difference there may be in the diameters, the resistance, or the causes of cooling, this equality of velocity, should there be any difference, will not exist; and if the section of each of them is equal to the section of the end tubes, the motion will take place through one only, that one which offers the least resistance. This phenomenon will evidently occur, whatever the number of the tubes may be.

19. If the pipe were only enlarged throughout a portion of its length, Fig. 1904, the current of heated air could not necessarily fill the enlarged portion of the pipe; if it filled it at first, the cooling of the sides would soon cause a decrease of temperature from the centre to the circumference; there would occur, in the elementary veins and in the same direction, variations of velocity which would go on increasing, so that the vein of heated air would soon traverse the enlarged space, without much increasing in section.




20. Suppose now that the heated air drawn by the chimney descends a pipe consisting of two parallel branches, Fig. 1905. In this case, the heated air will separate itself equally in the two branches, and the equality of velocity will be maintained in spite of the inequalities of cooling which the air may undergo. Indeed, in each branch, the force which produces the motion is equal to the difference of the pressures in the chimney and in the pipe under consideration, supposing them isolated; and, consequently, if in one of the branches the cooling was greater than in the other, the velocity there would become greater. The same thing would occur in the case of any number of parallel tubes.

21. If the pipe through which the heated air descends were enlarged, Fig. 1906, the elementary veins in the enlarged portion would assume and retain the same temperature, for the same reason as in the preceding case.

These facts, which have been many times proved by experience, are of great importance in the construction of heating apparatuses, as we shall see later.

22. It must be remarked that in all the preceding considerations relative to the velocity of the gases in chimneys, we have left out of the question the resistance experienced by the air when in motion. But as this resistance is always considerable, there will be a greater or less reduction of the velocity. When the descending pipe is single, friction takes place against the surface; therefore, on this account alone, the velocity would there be less than in the other points of the section; but the cooling which the heated air there undergoes tends to diminish the difference of velocity which would naturally arise in the veins, and this difference will be still more diminished by the gradual transmission of the resistance and the temperature. If the descending pipes were formed of several tubes having the same section and the same length, the same phenomena would occur, and the heated air would have the same velocity in each of them. But if the tubes have different sections, the velocity will be modified by the cooling which tends to increase it and by the friction which tends to diminish it. The friction varies in proportion to the square of the velocity, whilst the cooling is proportional to the diameter and depends also upon the velocity; it is, therefore, not

easy to foresee and to calculate in a general manner what will happen. The cooling is, however, small in general, and the influence of friction will in almost all cases exceed it, so that the actual velocity will decrease with the diameter of the pipes, a theoretical result that is in perfect accordance with the results of experience. The difference of the velocities will evidently decrease with the velocities themselves.

23. *Former Theory with respect to the Drawing of Chimneys.*—Hitherto it has been admitted that the force in air at $\theta^\circ$, $H a (t - \theta) + (1 + a t)$ was applied directly to the heated air, and the result of this was, that the force in air at $t^\circ$ being $H a (t - \theta) + (1 + a \theta)$, the velocity of the heated air was

$$v'_1 = \sqrt{\frac{2 g H a (t - \theta)}{1 + a \theta}};$$ and the rate of ingress of the cold air was

$$v_1 = v'_1 \frac{1 + a \theta}{1 + a t} = \sqrt{\frac{2 g H a (t - \theta)(1 + a \theta)}{(1 + a t)^2}},$$

formulæ which differ widely from the formulæ [A] and [B], for we have evidently

$$v'_1 = v' \sqrt{\frac{1 + a \theta}{1 + a t}}; \text{ and } v_1 = v \sqrt{\frac{1 + a \theta}{1 + a t}};$$

which give for $v'_1$ and $v_1$ velocities less than $v'$ and $v$. Besides this, the value of $v_1$ offers a circumstance that is not found in the value of $v$. If $\theta$ remaining constant, the value of $t$ be progressively increased, $v_1$ increases at first, reaches a maximum for $t = \frac{1}{a} + 2\theta = 274 + 2\theta$, and afterwards decreases indefinitely.

24. But the force in air at $\theta$ acts directly upon the cold air which is entering the chimney and not upon the heated air, and it is the velocity of the cold air that is afterwards transmitted to the heated air. Thus the formulæ which we have just given, for a considerable time admitted by all who have studied the question and by Péclet in the second edition of his work, do not represent the phenomena as they actually are. This discovery, due to Péclet, resulted from a more careful examination of the facts and from several experiments which we here relate, taken from Péclet's 'Traité de la Chaleur.'

25. Taking the case of a horizontal pipe through which air coming from a gasometer flows, let L and D denote the length and the diameter of the pipe; P the excess of pressure in the gasometer over the pressure of the atmosphere; $p$ the force corresponding to the velocity of flow at the end of the pipe, both expressed in air at the external temperature $\theta^\circ$; and A the coefficient of the loss of force at the orifice. The pipe being at the external temperature, we shall have

$$P - p = \left(A + \frac{K L}{D}\right) p, \text{ and } V = \sqrt{\frac{2 g P}{1 + A + \frac{K L}{D}}}. \qquad [a]$$

Suppose now the pipe heated so as to raise its temperature to $t^\circ$; admitting that the flow of heated air takes place by the force in heated air, this force will be $P \frac{(1 + a t)}{1 + a \theta}$, and the velocity of flow $v_1$ of the cold air from the gasometer will be

$$v_1 = \frac{1 + a \theta}{1 + a t} \sqrt{\frac{2 g P (1 + a t)}{1 + a \theta}} \cdot \frac{1}{1 + A + \frac{K L}{D}\left(\frac{1 + a t}{1 + a \theta}\right)^2}; \qquad [b]$$

and as, by placing the whole under the radical sign, the first factor becomes $2 g P \frac{1 + a \theta}{1 + a t}$, we see that the ratio of V to $v_1$ is greater than the square root of $\frac{1 + a}{1 + a \theta}$.

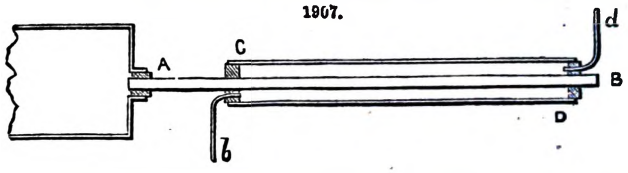
In the new theory, we have as the velocity $v$ of the cold air,

$$v = \sqrt{\frac{2 g P}{1 + A + \frac{K L}{D}\left(\frac{1 + a t}{1 + a \theta}\right)^2}}; \qquad [c]$$

and the ratio of V to $v$ decreases but slowly, in proportion as $t$ increases, and only by the increase of resistance due to friction, and which is caused by the elevation of the temperature.

26. To determine the influence of the heating of the air in the pipe A B, Péclet had recourse to the arrangement shown in Fig. 1907. A B is a copper pipe 1 mètre in length and $0^m \cdot 01$ in diameter, communicating with a gasometer; throughout a portion of its length it was enclosed by another concentric tube C D; the space between the two tubes was closed at the ends by cocks, and steam introduced by the pipe $a$, and let out by the pipe $b$.

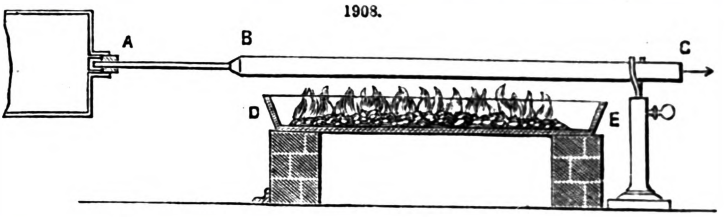
1907.




When the pipe A B was not heated, a certain volume of air flowed through in 612″; and when the pipe was heated, the same volume of air, under the same pressure and at the same temperature, flowed through in 618″.

27. To obtain a higher temperature, Péclet adopted the arrangement shown in Fig. 1908. A B is a glass tube of $0^m \cdot 322$ in length and $0^m \cdot 0047$ in diameter, fixed to the end of an iron tube B C of

1908.




$0^m \cdot 90$ in length and $0^m \cdot 011$ in diameter; beneath the iron tube was placed a stove D E of nearly the same length, for the purpose of holding burning charcoal. For this arrangement, the equations [a], [b], and [c] were replaced by the following:

$$V = \sqrt{\frac{2gP}{1 + A - B + \frac{Kl}{d} + \frac{KL}{D} \cdot \frac{d^4}{D^4}}} \qquad [a']$$

$$v_1 = \frac{1 + a\theta}{1 + at} \sqrt{\frac{2gP(1 + at)}{1 + a\theta}} \cdot \sqrt{\frac{1}{1 + A - B + \cdot \frac{Kl}{d} + \frac{KL}{D} \cdot \frac{d^4}{D^4} \left(\frac{1 + at}{1 + a\theta}\right)^2}} \qquad [b']$$

$$v = \sqrt{\frac{2gP}{1 + A - B + \frac{Kl}{d} + \frac{KL}{D} \cdot \frac{d^4}{D^4} \left(\frac{1 + at}{1 + a\theta}\right)}} \qquad [c']$$

in which V represents the velocity of flow in the small tube when the air is not heated; $v_1$ and $v$, the velocities of the cold air when the air is heated in the large tube, for the old and new theories; $l$, L, $d$, D, are the lengths and the diameters of the tubes A B and B C; A and B are the coefficients of the variations of force at the orifice, and at the point in which the tube is suddenly enlarged.

In this case, as in the preceding, the ratio of V to $v_1$ is greater than the square root of $\frac{1 + at}{1 + a\theta}$, whilst the ratio of V to $v$ differs but little from unity.

The iron tube being at the external temperature, a certain volume of air flowed through in 620″; and when it was heated to a dark red, the same volume of air, in the same circumstances, flowed through in 650″. The iron tube having been replaced by another of $0^m \cdot 013$ in diameter and $1^m \cdot 16$ in length, the same volume of cold air flowed through in 615″; and when the tube was heated red hot, the time of the flow, in the same circumstances, rose to 648″. The external temperature was at 14°.

These experiments do not enable us to determine exactly to which of the two formulæ [b] and [c] or [b'] and [c'] they conform most, because it was impossible to measure the temperature of the air on issuing, and because the increase of temperature took place successively, which prevented the calculation of the resistance in the tube A B. It is, however, plainly seen that the equations [b] and [b'] are incompatible with the equations [a] and [a'].

28. In the first experiment, the ratio of the velocities of the cold air, when the second tube is cold and when it is heated, is equal to $\frac{618}{612} = 1 \cdot 0099$; and, according to the formulæ [a] and [b], supposing the air at 100°, this ratio should be greater than the square root of $\frac{1 \cdot 366}{1 \cdot 0366}$, which is equal to 1·1471. Neglecting the increase of resistance in the tube A B, which increase augments the ratio in question, we should have to admit for formula [b], in order to make it agree with experience, $t = 15° \cdot 7$; but this is impossible, for the temperature must have been near 100°. In the second experiment, the ratio of the velocities in question was equal to $\frac{650}{620} = 1 \cdot 0483$; and, according to formula [b'], supposing only the air at 400°, this ratio should exceed the square root of $\frac{2 \cdot 464}{1 \cdot 05124}$, which is equal to 1·53. Neglecting the increase of resistance in the tube A B, to make formula [b'] agree with experience, we should have to suppose $t = 42° \cdot 4$. But this is impossible, for we find in the *register of the experiments* these words: *The air issuing is burning; a thermometer held in it rapidly rises to* 150°. And it could not have been otherwise, for the iron tube was red hot. In the third experiment, the ratio of the velocities was $\frac{648}{615} = 1 \cdot 0536$; and, according to formula [b'], supposing only the air at 600°, this ratio should exceed the square root of $\frac{3 \cdot 196}{1 \cdot 0512}$, which is equal to 1·743. Neglecting as before the increase of resistance in the tube A B, to make formula [b'] agree with experience, we should have to suppose $t = 45° \cdot 5$. This again is impossible, for the air issued hotter than in the preceding experiment.

The discrepancies which we have found between the results of the formulæ [b] and [b'] and those

of experience, are too great to be attributed to errors of observation. For example, for the first experiment, neglecting the resistance due to the increase of friction, the time of the flow should have been $612 \times 1{\cdot}1471 = 900''$, instead of $618''$; that is, greater by $900 - 618 = 282''$; and this difference should have been much greater for the others; now, each experiment was repeated twice with the same result each time.

29. It follows evidently from all these experiments that the formulæ [$b$] and [$b'$] cannot be admitted; that is, when air flows in a horizontal tube in virtue of a pressure, and the air at a certain distance is heated, the velocity of the cold air cannot be deduced from that of the heated air by taking as the force of this flow of cold air, the force in heated air. But if we suppose that the external force is applied to the cold air, the velocity will undergo only a small diminution resulting from the increased resistance of the heated air, and this agrees with the experiments.

That which we have just affirmed must evidently be true, whatever the nature of the pressure exerted on the cold air on its entrance into the tube may be; therefore, if it is vertical and heated externally, the pressure resulting from the two columns of air of the same height, one at the external temperature $\theta°$, and the other at the mean temperature $t$, is the force which acts directly on the cold air entering the chimney; this force should be measured in air at $\theta°$, and it is this velocity which is afterwards transmitted to the heated air, as we have already explained (3).

30. *Former Experiments on the Flow of Air in Chimneys.*—Many years ago Péclet made a long series of experiments on the flow of air in chimneys. He employed pipes of sheet iron, cast iron, and earthenware, of various heights and sections. The apparatus was arranged in the following manner: the stove was large and partly covered with charcoal for the purpose of rendering the resistance of the fire-place nearly nul; the chimney was above the stove. The temperature of the air in the chimney was shown by two thermometers placed, one at the bottom, the other at the top. As anemometers were unknown in those days, Péclet determined the velocity of the air by introducing rapidly through the opening in the ash-pan under the stove, a piece of burning tow which had been previously dipped in turpentine and fixed to the end of an iron rod. Withdrawing immediately the burning tow, a small quantity of smoke was produced in the fire-place and carried upwards by the heated air. By observing the time when the smoke was produced and the time when it appeared at the top of the chimney, the velocity of the current of air in the chimney was ascertained. The experiments were repeated with the chimney more or less closed at the top, and at the bottom by diaphragms formed of a sheet of iron pierced with a circular orifice. The method of observation was too imperfect to give exact results, yet these experiments enabled the experimenter to ascertain some important facts of which we will speak later.

31. *General Considerations on Factory Chimneys.*—In order to study in a complete manner the phenomena which occur in chimneys, it is necessary to have a clear notion of the general arrangement of heating apparatuses. As we have said already, they consist of the furnace, the space in which the heat is utilized, and the chimney. Furnaces are usually formed of cast-iron bars placed in a horizontal plane, or slightly inclined, separated from each other by small intervals, and upon which the fuel is placed. Beneath is a space communicating freely with the air, and known by the name of the "ash-pit."

The space comprised between the furnace and the chimney, and where a portion of the heat produced passes into the body which it is wished to heat, has forms and dimensions varying with the nature of the effect to be produced.

Chimneys are always vertical tubes or channels, constructed of brick or sheet iron, and designed to discharge the burned air, and to create a draught through the furnace, which draught is necessary to support combustion.

32. The inward rush of external air caused by the temperature of the burned air and by the height of the chimney is called the *draught*. The draught of a chimney, as we have calculated it, is always diminished, in a very large proportion, by the resistance of the bars, and so on, of the furnace, the sudden or continuous changes of section and direction, and by friction.

The phenomena which occur in heating apparatuses are very complicated and very varying, chiefly with the condition of the furnace; but we may determine the influence of the various circumstances which modify the draught. We will suppose, in the first place, that the circuit has everywhere the same section, from the opening of the ash-pit to the top of the chimney. This hypothesis differs but little from ordinary facts; even to the sum of the free orifices of the furnace-bars a surface is given differing but little from the horizontal section of the chimney. Denoting, then, the section of the air-channel which conducts the air under the furnace-bars by S, the rate of ingress of the cold air by $v$, S$v$ will represent the volume of cold air entering per second. Putting G for the resistance of the furnace, C for that of the circuit preceding the chimney, and H and D for the height and diameter of the chimney, the friction in the chimney will be $\mathrm{K\,L}\,(1+at)^2 \div \mathrm{D}\,(1+a\theta)^2$, and would be exactly the same if the section of the chimney were the square circumscribed about the circle. Applying here the laws relative to the motion of compressed gases, we shall have, supposing the temperature outside equal to 0°

$$\mathrm{P} - p = (\mathrm{G} + \mathrm{C})\,p + \frac{\mathrm{K\,H}}{\mathrm{D}}(1+at)^2 p\,;$$

whence

$$v = \sqrt{\frac{2g\mathrm{H}at}{(1+at)\left[1 + \mathrm{G\,C} + \frac{\mathrm{K\,H}}{\mathrm{D}}(1+at)^2\right]}}.$$

33. The examination of this formula leads to several consequences of great importance in practice.

1. When the values of G and C are very great relatively to the friction in the chimney, which is almost always the case, the draught is proportional to the square root of the height.

2. If we supposed G and C nul, which would happen only in the case in which the furnace is placed at the bottom of the chimney, the grating occupying only a small portion of the section, and the air experiencing no resistance on entering the chimney, the draught would vary very little with the height of the chimney; it would be nearly independent of it when $KH + D$ is very great relatively to 1. These are circumstances which occur rarely in practice, but they were present in the experiments to which we have alluded (30). The height of the chimney had hardly any influence upon the draught, because the air experienced hardly any resistance.

3. Suppose again that, nothing being changed in the dimensions of the apparatus, the temperature $t$ varies. If G and C be supposed constant, the friction in the chimney being in general very small relatively to G + C, the draught, will vary nearly proportionally to the square root of $\frac{t}{1+at}$, that is, in the same ratio as the theoretical draught. Thus, in the supposition which we have made, the ratio of the actual to the theoretical draught would be a constant number, depending only on the dimensions of the apparatus. But, in an apparatus in operation, $t$ can rise only by the increase of the velocity of the current, and this increase can take place only by the diminution of the resistance, which, in the case supposed, can result only from the condition of the furnace or from the raising of the register; the draught in that case increases in a greater ratio than in the supposition of G and C constant, only there is at the same time a certain increase in the value of C, resulting from the increased velocity. In like manner, the value of $t$ could decrease only by the increase of resistance in the grating, or by the lowering of the register, and the diminution of draught would then be more rapid than if the resistance did not vary.

34. Let us now see what would happen if the circuit were interrupted by a diaphragm. This is a circumstance that occurs in every heating apparatus, for all are provided with registers for the purpose of regulating the draught or of stopping it altogether during the interruptions of work. We will first suppose that the diaphragm is placed in that portion of the air-channel which conducts the external air beneath the grating. Denoting the orifice in the diaphragm by $d$ its diameter, we shall have

$$P - p = (G + C)p + \frac{KH}{D}(1+at)^2 p + \left(\frac{D^4}{d^4} - 1\right)p;$$

$$\text{whence } v = \sqrt{\frac{2gHat}{1+at}}\sqrt{\frac{1}{1+G+C+\frac{KH}{D}(1+at)^2+\frac{D^4}{d^4}-1}}$$

neglecting the loss at the entrance into and the gain at the issue from the orifice, which are both very small relatively to the denominator of the second radical in the value of $v$.

It follows from this formula that the influence of the diaphragm becomes smaller as the total resistance of the circuit becomes greater. In large steam generators, the actual rate of ingress is less than a fifth of the theoretical rate. Supposing it equal to this fraction, we shall have nearly

$$v = \sqrt{\frac{2gHat}{1+at}}\sqrt{\frac{1}{25+\frac{D}{d^4}-1}}.$$

If we suppose that the ratio of the sections of the chimney and of the orifice $\frac{D^2}{d^2}$ becomes successively, 2, 4, 6, 8, 10, 20, 40, 60, 80, 100; the values of the second radical will be 0·189, 0·158, 0·130, 0·1066, 0·09, 0·048, 0·025, 0·0166, 0·0125, 0·01. The value of the radical without the diaphragm is 0·20, and by the influence of the diaphragm it is reduced in the proportion, 0·945, 0·75, 0·64, 0·53, 0·45, 0·24, 0·12, 0·083, 0·062, 0·059. Thus, as it was easy to see by inspection from the formula, diaphragms diminish the draught in a proportion much smaller than the ratio of the sections; a diaphragm which reduces the section to a tenth reduces the draught by only the half. This small influence is due to the retardation of the velocity by the diaphragms, and, consequently, the diminution of resistance in the rest of the circuit.

35. The diaphragm reducing the rate of flow in a proportion less than the ratio of its section to that of the chimney, it follows that the velocity of the air in the orifice of the diaphragm must increase in proportion as its surface decreases. In the general case, the velocity of the air in the diaphragm is:

$$v = \sqrt{\frac{2gHat}{1+at}}\cdot\frac{D^2}{d^2}\cdot\sqrt{\frac{1}{1+G+C+\frac{KH}{D}(1+at)^2+\frac{D^4}{d^4}-1}};$$

and in the particular case which we have examined, we have

$$v' = \sqrt{\frac{2gHat}{1+at}}\sqrt{\frac{\frac{D^4}{d^4}}{25+\frac{D^4}{d^4}-1}}.$$

Taking as the ratio of the sections $\frac{D^2}{d^2}$ the same numbers as before, we find as the value of the second radical, 0·378, 0·632, 0·77, 0·85, 0·90, 0·97, 0·992, 0·996, 0·998, 0·999 and as the value

of this radical without the diaphragm is 0·20, the velocities in the diaphragm with respect to the velocity in the circuit are, 1·89, 3·16, 3·87, 4·26, 4·49, 4·85, 4·96, 4·98, 4·99, 4·99.

Thus this ratio approaches 5 as the diameter decreases, because the actual velocity without the diaphragm is $0{\cdot}2 = \frac{1}{5}$ of the velocity due to the force, and, the diaphragm retarding the velocity in the chimney, diminishes the friction. It is evident that if the velocity of the current of air were a fraction $\frac{1}{m}$ of the velocity V due to the force, the ratio in question would continually approach $m$ as the diameter of the diaphragm diminished.

36. If there were in that portion of the air-channel which conducts the air to the ash-pit several diaphragms at a sufficient distance apart to allow the vein of air, after having traversed each of them, to fill the space in which they are placed before meeting with the next, the velocity would become

$$v = \sqrt{\frac{2gHat}{1+at}}\sqrt{\frac{1}{1+G+C+\frac{KH}{D}\quad+at)^2+m\left(\frac{D^4}{d^4}-1\right)}},$$

and if $\frac{D^4}{d^4}$ were very great relatively to the terms which precede, for the same value of $\frac{D^2}{d^2}$ the value of $v$ would vary in an inverse proportion to the square root of $m$.

37. We have supposed that the diaphragms were placed in the current of cold air before it reached the grating of the furnace; let us now suppose them placed in that portion of the circuit traversed by the heated air. As the velocities are inversely as the densities, we shall have in general

$$P-p = (G+C)p + \frac{KH}{D}(1+at)^2p + m\left(\frac{D^4}{d^4}-1\right)(1+at)^2p;$$

$$\text{whence } v = \sqrt{\frac{2gHat}{1+at}}\sqrt{\frac{1}{1+G+C+\frac{KH}{D}(1+at)^2+m\left(\frac{D^4}{d^4}-1\right)(1+at)^2}}.$$

Thus diaphragms placed in the current of heated air reduce the draught more than when they are placed before the ash-pit, because the velocity of the heated air is greater than that of the cold air.

38. Experiments made by M. Combes confirm the consequences which we have drawn from the general formula. It was found that by closing the orifice for the ingress of the air into the ash-pit of a generator, by means of a sheet of iron pierced with holes, the velocity of the air traversing the aperture, measured by an anemometer, continued to increase with the decrease of the size of the holes. The following are the details of this experiment.

The chimney was 20 mètres in height; its section at the bottom being 0·383 square mètre, and at the top 0·196 square mètre. The surface of the furnace-grating was 0·6525, and the sum of the spaces between the bars 0·168 square mètre. The mouth of the ash-pit was covered with a sheet of iron pierced with six square holes of $0^m{\cdot}167$, and having a surface of 0·028 square mètre each, and altogether a surface equal to the whole open surface between the bars.

The velocity was first ascertained by means of an anemometer with all the holes open, immediately after the fire had been made up, and again after it had been stirred. Two experiments made in succession gave as the velocities $0^m{\cdot}5275$, $1^m{\cdot}68$, $0^m{\cdot}86$, $1^m{\cdot}15$; mean, $1^m{\cdot}17$. With two of the holes closed, under the same circumstances, the velocities were 1·607, 1·99, 1·89, 2·05; mean, $1^m{\cdot}88$.

When four of the holes were closed, the velocities under the same circumstances were 3·51, 4·05, 2·68, 3·46; mean $3^m{\cdot}42$.

In these three series of experiments, the surfaces for the ingress of the air were $0{\cdot}168 \times 0{\cdot}65 = 0{\cdot}1092$; 0·0728 and 0·0364 square mètre; and the mean velocities 1·17, 1·88, and $3^m{\cdot}42$. Thus the velocities increase rapidly with the decrease of the sections of the orifices; for orifices in the proportion of 3, 2, and 1, the velocities increased 1·26, 1·65, 3.

39. *Lateral Pressure in Chimneys.*—Suppose a chimney placed beyond a furnace of any form, and an opening made in it at a certain height; it is evident that the external air will enter with a velocity greater in proportion to the nearness of the aperture to the ground. At the top, this velocity is nul. This rush of external air would occur if the aperture were in any part of the heating apparatus. Therefore care should always be taken in building to avoid an ingress of external air through fissures in the masonry, because they always occasion a loss of draught and often diminish the useful effect of the fuel.

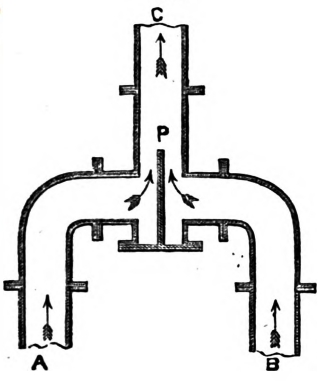
40. It follows necessarily from what we have said, that inside the furnace and chimney there is a negative pressure, that is, smaller than that of the atmosphere, and that this negative pressure continues to increase from the ash-pit to the bottom of the chimney, and decreases in like manner to the top of the chimney where it is nul.

41. *Effects produced by the Meeting of Currents.*—When several pipes enter the same channel the currents of air project themselves beyond the orifices, and in certain circumstances they may by their mutual action, modify the velocities of the air in the pipes. If, for example, two pipes entered a third exactly opposite each other, the third pipe being perpendicular, the influence of the currents would be nul if they had the same velocity; for the effect would be the same as if the currents flowed against a fixed plane placed between them. But if the velocities were unequal, the current having the greater velocity would diminish that of the other, and close more or less, the orifice through which it flowed. A vast number of phenomena leave no doubt on this fact;

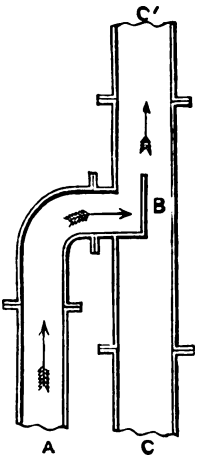
besides, these currents must act upon each other in nearly the same manner as currents of water, and it is known, from the experiments of Savart, that when two currents of the same section act in contrary directions and one of them has a very small excess of velocity over the other, the latter is driven back to the mouth of the vase, and the flow ceases completely. The effects resulting from this collision may be prevented by placing in the pipe a diaphragm P, as shown in Fig. 1909.

42. Phenomena of the same kind would occur if the two pipes were at right angles to each other, Fig. 1910, with the additional complication caused by the effect of the lateral pressure. But these effects may be wholly avoided by means of the diaphragm P.

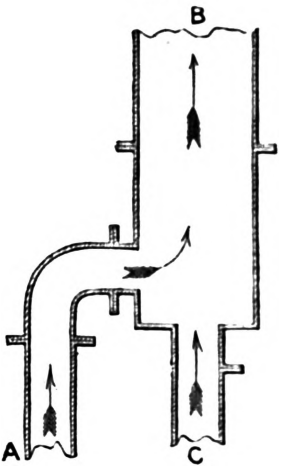
1909.




1910.



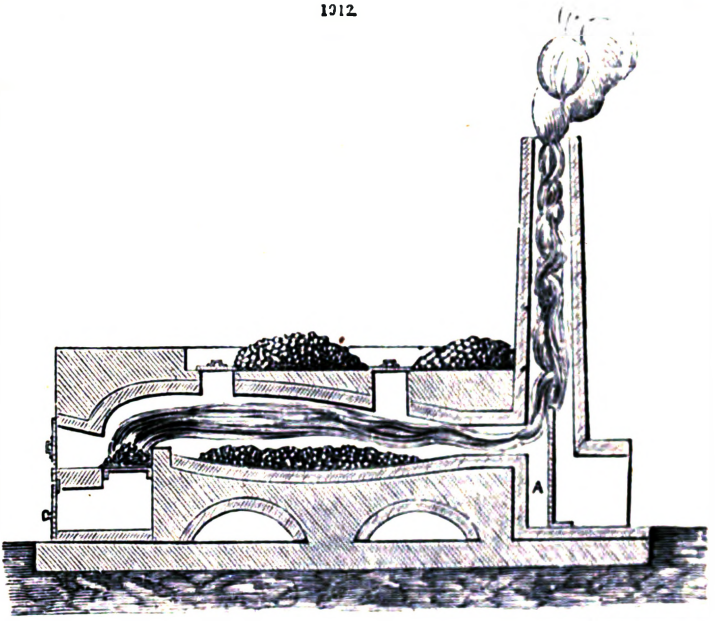

1911.




If the pipe were enlarged, as in Fig. 1911, the narrowing of the pipe in front of mouth of the lateral pipe would have the effect of a diaphragm; the influence of the collision of the currents might be neglected, but that of the diminution of pressure, due to the enlargement of the pipe, might be very great.

43. In the case of a current of heated air flowing horizontally into a vertical chimney, it may happen that the draught is completely stopped, though the section of the chimney is larger than that of the current of heated air, when the velocity of the latter is very great, because in that case it will close the chimney like a plug. This is a fact which Péclet has had occasion to remark several times, and especially in the case of a chimney which he had built in a soda manufactory, and which formed a portion of a condensing apparatus. This chimney was $13^{m}\cdot30$ in height, and had a section of about $0\cdot75$ square mètre; the smoke-channel entered it horizontally, Fig. 1912. When the fire in the furnace was kindled, the draught existed: it increased for some time, and then gradually decreased, till finally it ceased. Péclet soon discovered the cause of this singular phenomenon, and removed it by a vertical partition A placed in the chimney so that the heated air did not come in contact with the gases of the chimney until it had taken the same upward direction.

1912.




Thus, it is necessary to take the greatest care, in all draught chimneys which receive currents of air perpendicularly or variously inclined, to direct them according to the axis of the chimney before they come in contact.

44. *Loss of Heat occasioned by Chimneys.*—The quantity of heat lost by chimneys is very considerable, because the burned air is allowed to escape at very high temperatures, always higher than that of the heated body. This quantity varies with the temperature of the air which escapes, with the volume of cold air entering the furnace, and with the weight

of water contained by the fuel, or produced by its combustion, for the gases are almost always evolved at too high a temperature to allow the condensation of the steam. This loss may be computed approximatively, however, by comparing the temperature of the burned air in the chimney with that which it would have if all the heat produced were employed to heat it. In this calculation it may be assumed that the burned gases possess the calorific capacity of air.

For example, in steam generators the burned air is discharged at about 300°, and on an average 18 cubic mètres of air is employed per kilogramme of coal, or $18 \times 1{\cdot}3 = 23^{k}{\cdot}4$; taking 0·24 as the calorific capacity of the gases produced, the temperature to which the gases would be raised by the 8000 calories or units of heat, resulting from combustion, would be equal to $8000 \div (23{\cdot}4 \times 0{\cdot}24) = 1425°$; consequently, the loss is equal to $300 \div 1425 = 0{\cdot}21$. This loss would evidently be doubled or trebled if twice or three times the quantity of air were employed, and it would be reduced to 0·1 if only that volume of air were employed which is rigorously necessary to combustion. Under ordinary circumstances, the loss must be reckoned at not less than 0·25, on account of the steam produced.

In furnaces for melting metals and for the production of coal-gas, the burned air is allowed to escape at a much higher temperature, on account of the high temperature of the substances heated, and the loss of heat is much greater. The loss often amounts to 0·80 or 0·90, even when the volume of air which escapes combustion is very small; but the heat thus lost may, in general, be utilized, at least in a great measure. The utilization of this lost heat is a question of the highest importance in factories, for the cost of fuel is nearly always a considerable item in the cost of the productions. We will return to this subject later.

45. *Arrangements for utilizing the whole of the Heat produced by a Furnace.*—In the apparatus generally employed, the chimney is placed beyond the furnace, which causes, as we have seen, a loss of heat that may be avoided by certain arrangements.

Let us suppose that above or beyond a furnace, well enclosed, there is a chimney of 3 or 4 mètres in height, of considerable thickness, and constructed of badly-conducting material. The burned air in this chimney will have a very high temperature, and will acquire an ascending velocity much greater than that necessary to support combustion. Suppose, again, that above this chimney, in its continuation or at the side of it, is the boiler or body to be heated: the course of the smoke may be lengthened, so as to cool it completely or almost completely; and on leaving the heating surfaces it may be allowed to escape immediately into the air, or conducted to a chimney, the use of which is merely to discharge it at a convenient height in the atmosphere.

A similar arrangement is adopted in certain kinds of glass-works; the height of the draught chimney is equal to the distance from the furnace-grating to the roof of the furnace, and the burned air may give up all its heat in the arch if the latter is of sufficient length.

46. At first sight, this method seems applicable only when the bodies to be heated are to be raised to a temperature exceeding but little the ordinary temperature, since the burned air cannot be ejected at a temperature lower than that of these bodies. But by moving the bodies to be heated in a direction contrary to the motion of the heated air, it is evident that, in almost all cases, nearly the whole of the heat of this air may be utilized, and the temperature reduced to that of the atmosphere.

47. This method, which consists in placing the chimney in front of the heating surface, has a disadvantage which we ought to point out. The heating surface must be larger than in the ordinary arrangement, because it is not heated directly by the radiation of the fuel; notwithstanding this disadvantage, however, there are many cases, as we shall see later, in which this method may be adopted with profit.

48. The apparatus may be arranged so as to produce the draught through the heating surface. The arrangement consists in placing the body to be heated in the chimney. If the channels of circulation are narrow, and the heating surface large, the burned air will reach the top of the chimney at a temperature but little above that of the heated body, although the draught be very strong, because the ascending velocity will depend on the mean temperature of the burned air in the channels of circulation, and the temperature at the bottom will be that of the furnace. This arrangement is seen in lime-kilns.

49. *Dimensions of Factory Chimneys.*—The work of a chimney consists, as we have said, in drawing into the furnace the volume of air necessary to combustion. The weight of fuel to be burned an hour is always given; the height of the chimney is, in general, determined by particular conditions, but the section depends on the volume of air employed in consuming each kilogramme of fuel, on the mean temperature which the air will have in the chimney, on the loss of force occasioned by friction, on the changes of section and direction, and on the resistance of the furnace-grating. The phenomena occurring in the draught of a heating apparatus are so complicated, that we cannot hope, by means of simple theoretical considerations, to calculate exactly and for every case the section which should be given to a chimney to produce a given effect. These calculations would be rendered more inexact by the facts that we do not know beforehand the temperature of the air in the chimney, the mean temperature of the air which circulates around the body to be heated, nor the resistance of the grating, and that these three elements, which it would be necessary to know before calculating anything, vary with the condition of the fuel in the furnace, and with its thickness upon the grating. Thus, in every case, we must consider the results of experience to ascertain what section should be given to a chimney; but it is important to remark that there will always be an advantage in giving to chimneys an excess of section, because this produces an excess of draught which may be necessary in certain cases, and which may always be regulated by means of a register.

50. For fixed steam generators, arranged in the usual way, Péclet discovered, by bringing together a large amount of information, and by some experiments, that for chimneys having 10, 20, and 30 mètres, containing air at 300°, with gratings, the open spaces of which are equal to the section of the chimney, and upon which is burned 1 kilogramme of coal an hour per square deci-

mètre, circumstances of ordinary occurrence, the rate of ingress of the cold air is about $0{\cdot}18\,v$, $0{\cdot}17\,v$, $0{\cdot}16\,v$, $v$ being the theoretical rate.

For the heights of 10, 20, and 30 mètres, which we have supposed, and for a mean temperature of 300° in the chimney, the rates of ingress of the cold air, deduced from the formula $V = \sqrt{\frac{2gHat}{1+at}}$, are 10·13, 14·33, 17·55 mètres, and, consequently, the actual rates are $0{\cdot}18 \times 10{\cdot}13 = 1{\cdot}82$, $0{\cdot}17 \times 14{\cdot}33 = 2{\cdot}44$, $0{\cdot}16 \times 17{\cdot}55 = 2{\cdot}80$. The volumes of air drawn an hour per square decimètre of section being $v \times 0{\cdot}01 \times 3600$, will be for the three heights, 65·52, 87·84, 100·8 cubic mètres; and assuming that only the half of the air is transformed into carbonic acid, and, consequently, that the volume of air required to burn 1 kilogramme of coal is equal to 18 cubic mètres, the weight of coal an hour per square decimètre of section will be represented by the preceding numbers divided by 18, that is equal to 3·42, 4·71, 5·50 kilogrammes. These numbers differ but little from those adopted by the most experienced engineers; by employing them we may be sure of having a considerable excess of draught, but no disadvantage can result from this, as we have shown above.

The proportion of the section of the chimney to the consumption of fuel necessarily supposes that the resistance remains constant, an hypothesis that may be admitted; for the resistance caused by the grating and by changes in the direction of the current, undergoes but little variation, and that occasioned by friction has, in general, but little influence on the total resistance.

51. According to the foregoing, denoting the sum of the resistances experienced by the air in its course by R, we have in the three cases considered,

$$v = 0{\cdot}18\,V = V\sqrt{\frac{1}{1+R}};\quad v = 0{\cdot}17\,V = V\sqrt{\frac{1}{1+R}};\quad v = 0{\cdot}16\,V = V\sqrt{\frac{1}{1+R}};$$

and the values of R are 29·98, 33·49, 38·29. These numbers represent the sum of the resistances due to friction, to changes of direction, and to the grating.

Comparing the dimensions of a large number of generators, we find that, for the three heights of chimney given above, the values of $\frac{KL}{D}$ are equal to 1·5, 2·37, 3·57: as there are usually eight changes of direction at right angles, assuming that these changes take place in a continuous manner, the corresponding losses would be represented by 4; and considering the velocity in the chimney as double that of ingress, which is not far from the truth, the sum of these two kinds of resistances would be $5{\cdot}5 \times 4$, $6{\cdot}37 \times 4$, $7{\cdot}57 \times 4$, or 22·0, 25·48, 30·28; the resistance of the furnace would then be represented by 8. But these calculations must be considered as only rough approximations, sufficient to give an idea of the value of the different kinds of resistance which take place.

52. *Sections of the Chimneys of Generators for different kinds of Fuel.*—Let us consider two generators having the same form and dimensions, the furnaces of which are supplied with different kinds of fuel, containing only carbon and fixed matter. It is evident that, if for each of them the same portion of air escaped combustion, the phenomena would be the same; the only difference would be that resulting from the unequal quantities of radiated heat, and from the unequal resistance of the furnace; but these differences would be of small importance, and could occasion but little in the weight of carbon burnt a square decimètre of chimney. But if one of the kinds contain water or produce it, the sections of the chimneys, for the same weight of fuel, will no longer be the same. In this case, we may admit, as an approximation sufficient for practice, that the sections of the chimneys are proportional to the volumes of the gases to which they are to give a passage for the combustion of the same weight of the different kinds of fuel. If we denote by S the section of chimney necessary to consume a weight P of coal, by S′ the section of chimney corresponding to the combustion of a weight P of another kind of fuel, by V and V′ the volumes of the gases which are evolved by the combustion of a kilogramme of the two kinds, we shall have $S' = \frac{S \times V'}{V}$; from this we obtain the following results:

Dry wood .. .. .. .. .. .. $S' = S \times \frac{10{\cdot}08}{17{\cdot}28} = 0{\cdot}59 \times S.$

Wood with 0·20 of water .. .. .. $S' = S \times \frac{7{\cdot}42}{17{\cdot}28} = 0{\cdot}43 \times S.$

Dry turf with 0·05 of ashes .. .. $S' = S \times \frac{12{\cdot}01}{17{\cdot}28} = 0{\cdot}69 \times S.$

Turf with 0·20 of water .. .. .. $S' = S \times \frac{8{\cdot}78}{17{\cdot}28} = 0{\cdot}51 \times S.$

Charcoal .. .. .. .. .. .. $S' = S \times \frac{15{\cdot}28}{17{\cdot}28} = 0{\cdot}88 \times S.$

Coke with 0·02 of ashes .. .. .. $S' = S \times \frac{17{\cdot}40}{17{\cdot}28} = 1{\cdot}00 \times S.$

Coke with 0·15 of ashes .. .. .. $S' = S \times \frac{15{\cdot}10}{17{\cdot}28} = 0{\cdot}87 \times S.$

These numbers necessarily suppose that the resistance of the gratings is the same for all kinds of fuel; this is not strictly true, for all kinds of fuel do not encrust the bars so much as most

kinds of coal; but, as we shall see later, smaller surfaces of grating are employed for coke, wood, charcoal, and turf, so that the resistance of the gratings ought not to differ much. They suppose also that the other resistances do not change with the section, for it is on this condition that the volumes of air are proportional to the sections; but when the forms of the generators are alike, there is the same number of changes of direction, and the differences of section have only a small influence on the total resistance. But these numbers must be considered as approximative values, representing, however, sections producing an excess of draught.

53. It is important to examine what would happen if the chimney only or the whole of the circuit had a section greater than that resulting from the preceding considerations.

Suppose, in the first place, that a larger section is given to the chimney alone; the draught will increase on account of the expansion which the heated air will undergo on entering it, and on account of the diminution of friction. But in general this increase of draught will be small, and, if the chimney is too large, the velocity of the heated air may be diminished to such a degree, that the draught will be modified by the influence of the wind. It might even happen, if the section of the chimney were much too large, that the current of heated air did not completely fill it, and in that case downward currents of air would be caused which would greatly diminish the draught. To remedy this, it would be necessary to reduce the section of the chimney by a register placed in the upper portion.

If, on the contrary, the section of the chimney were diminished so as to make it much smaller than that of the gatherings, there would be a loss of force which could be compensated only by an increase of temperature of the heated air. Even this compensation could not be effected without difficulty and would be confined within narrow limits.

54. If the gatherings, the furnace-grating, and the chimney had a section much larger than those we have indicated, it is evident that, for a constant consumption of fuel obtained by closing the register in a greater or less degree, the resistance would diminish in proportion as the section increased, and finally we should obtain as the rates of ingress and egress of the gases the theoretical rates. To effect this, it would not be necessary to make the diameter of the air-channel very large; for if it were only five times the diameter calculated, the velocities would be twenty-five times smaller, and every kind of resistance $25 \times 25 = 625$ times less. This would be, therefore, a certain means of suppressing every kind of resistance; but in that case, to protect the draught from the influence of the wind, the register would have to be placed at the top of the chimney. This arrangement would largely increase the cost of construction and the loss of heat; for this reason it is never adopted.

55. *Various Methods that have been proposed to determine the Section of Chimneys.*—Montgolfier was the first who endeavoured to determine the section of a chimney, taking as starting-points its height, the volume of air necessary to combustion, and the temperature of the burned air. But he did not consider either the friction of the air against the sides or the resistance of the grating. The section thus determined was much too small.

Clement, in his lectures at the Conservatoire, gave Montgolfier's method; but he took only the fifth of the velocity calculated, which gave too large a section. Tredgold, in his 'Treatise on the Steam Engine,' gives a complicated method founded upon singular suppositions. He starts from the theoretical velocity, on the supposition that for boilers the temperature of the smoke is equal to that of the steam, and he multiplies the velocity obtained by 0·65, which represents the flow of air through orifices in a thin material.

According to M. Darcet, chimneys should be 10 mètres in height, and have a section such that each square decimètre may correspond to a consumption of 3 to 3·3 kilogrammes of coal an hour; the surface of the furnace-grating should be three times greater than the section of the chimney. These results differ but little from those we have indicated.

56. *Influence of the cooling of the outer surface of Chimneys upon the Draught.*—It might be thought that in isolated chimneys, traversed by air at a temperature of about 300°, the quantity of heat emitted by the surface being considerable, the air undergoes a great lowering of temperature, which must diminish the draught; but this is not the case. The quantity of heat carried away by the heated air is always very great relatively to that lost through the surface of the chimney, and the cooling of the air has no appreciable effect. Let us, by way of example, consider a chimney of 20 mètres in height, $0^{m}\cdot5$ in diameter, and 0·196 square mètre in section, containing air at 300°. The theoretical rate of ingress of the cold air through a channel having the section of the chimney will be $11^{m}\cdot93$, the actual rate $11\cdot93 \times 0\cdot165 = 1^{m}\cdot968$, the volume of air entering an hour, $1\cdot968 \times 3600 = 7084$ cubic mètres, the weight of which is $7084 \times 1^{k}\cdot3 = 9209$ kilogrammes and the quantity of heat carried away an hour about $9209 \times 300 \div 4 = 553175$ units of heat. Now, according to the formulæ of the cooling, which we shall see later, the quantity of heat emitted an hour, a lineal mètre, under these conditions, is 1587; for the 20 mètres, therefore, the loss will be $1587 \times 20 = 31740$. The ratio of 31740 to 553175 is 0·057. Thus the loss of heat through the chimney is not $\frac{1}{600}$ of the heat carried away by the air; consequently, the temperature of the air will not be lowered by 0·06—that is, it will remain above 282°, and the draught will not be affected in an appreciable degree.

57. For an iron chimney of the same dimensions, the quantity of heat emitted would be, according to the formulæ, 8037 a lineal mètre, and 160740 for the 20 mètres. The ratio of the heat lost to the heat carried away by the air would then be $160740 \div 553175 = 0\cdot29$. Thus, the temperature would be reduced by 87°, and the heated air would escape at about 213°, which corresponds (10) to a diminution of 0·1, nearly, in the draught.

58. *Calculation of the Diameter of Chimneys in the general case.*—All that we have said respecting the section of chimneys, designed to produce the combustion of a given weight of fuel, is applicable only to chimneys of fixed generators in ordinary conditions, when the temperature of the air is about 300°, and when about 1 kilogramme of coal is burned an hour and on a square decimètre of surface of grating. But, if the circumstances were different, the sections recommended would not

be suitable. As it is of great importance to be able to calculate them, at least within a certain degree of approximation, in every case that may occur, Péclet has endeavoured to find a simple method of accomplishing it.

59. We will suppose that the consumption of coal a square decimètre of grating is always about 1 kilogramme an hour. We have seen (51) that, for generators having chimneys of 10, 20, and 30 mètres in height, the resistance is about equal to 8.

Supposing the section of the air-channel constant and square, and denoting its length by L, the side by D, the number of changes in direction at right angles by N, we shall have as the rate of ingress of the cold air,

$$v^2 = \frac{2g\,H\,a\,t}{1+a\,t} \cdot \frac{1}{1+8+\left(\frac{K\,L}{D}+N\right)(1+a\,t)^2}. \qquad [1]$$

But denoting by V the volume of cold air required a second, which volume may be easily deduced from the weight and nature of the fuel to be consumed in the same time, and by S the section of the conduit, we shall have

$$V = S\,v; \text{ and } v^2 = \frac{V^2}{D^4}. \qquad [2]$$

Equating the values of $v^2$ in the equations [1] and [2],

$$V^2 = \frac{2g\,H\,a\,t}{1+a\,t} \cdot \frac{D^4}{9\,D+(K\,L+N\,D)\,(1+a\,t)^2},$$

if $t$ were known, putting in the place of V, $g$, H, $a$, N, their values, the last equation would assume the form

$$D^5 = A + B\,D, \qquad [3]$$

an equation that may be solved approximatively, by neglecting at first A or B, substituting the value of D, thus found, for D in the second member of equation [3], and successively for D the last value obtained, until two consecutive values differ only by a quantity smaller than the approximation required.

If the temperature $t$ were not known, we should have to assign to it a certain value found by experiments on similar apparatus. We will remark here that great accuracy in the value of $t$ is of no importance; for, as we have seen (10), the draught varies only in the ratio of 57 to 71, for $t = 159°$ and $t = 300°$.

60. As an example of these calculations, suppose it be required to burn 50 kilogrammes of coal an hour; let L = 40 mètres, $t$ 150°, and let there be ten changes of direction at right angles, we shall have $V = 50 \times 18 \div 3600 = 0{\cdot}25$; $2g\,H\,a\,t = 161{\cdot}40$; $1 + a\,t = 1{\cdot}55$; $K\,L = 0{\cdot}96$; and the formula [3] becomes $D^5 = 0{\cdot}00057 + 0{\cdot}0114\,D$. Neglecting, at first, the first term, and operating by successive approximations, we find for D the values 0·325, 0·335, 0·337, 0·338, 0·338. Thus the second substitution gives the value of D within a centimètre. The section being about 13 square decimètres, the consumption of fuel the square decimètre would be about 3 kilogrammes.

61. We have supposed that the resistance of the furnace-grating was constant and equal to 8; this will be the case when the consumption of coal the square decimètre and by the hour, is 1 kilogramme. If this consumption were less, the velocity of the air traversing the grating would be smaller, as well as the resistance, and consequently the section of the chimney calculated in the manner described would be too large. In the contrary case, it would of course be too small. In every case, it may be admitted that the resistance of the grating is proportional to the square of the velocity of the air traversing it; thus, denoting by $n$ the number of kilogrammes of coal burned an hour the square decimètre, the resistance would be equal to $8n^2$.

62. The results of these calculations must be considered as only approximative, because they rest upon hypotheses relative to the resistance of the grating and to the temperature of the air in the chimney, and because the numbers admitted may therefore be considerably from the truth.

63. The preceding remarks suppose not only that the air-channel retains its section throughout, but that it is not divided into several branches traversed simultaneously by the gases from the furnace. For if it were so, the sum of the resistances in the partial channels would be greater than that which the air would meet with in a single channel having the same section. When the air traverses simultaneously a large number of equal pipes, as in locomotive engines, the resistance is represented by $K\,l \div S^2 \div d\,S_1^2$, or by $K\,l\,D^4 \div n^2 d^5$, S denoting the section of the whole channel, $S_1$ that of the tubes, D the diameter of the channel, $d$ that of the tubes, and $n$ the number of the tubes.

64. If in a long circuit, from a generator or any other apparatus, there happened to be a number of tubes, we could not, without modification, employ the method indicated (59), to calculate the diameter of the chimney, because this method supposes the channel single throughout its length and constant in section. It might, however, be used tentatively. In fact, the resistance of a number of tubes is equivalent to that of a single pipe of a diameter D, the L of which is given by the equation

$$\frac{K\,l\,D^4}{n^2 d^5} = \frac{K\,L}{D}; \text{ whence } L = \frac{l\,D^5}{n^2 d^5}. \qquad [a]$$

Taking first a certain approximative value of D, we deduce from it the value of L by means of the equation [a]; the equation [3] (59) will give a new value of D, which will enable us to find a new value of L, and so on, till a constant value of L is found, and consequently of D. Besides, as in general we need only a rough approximation, and as in generators with tubes the course of the smoke is always very short, the increase of resistance in the tubes is nearly compensated by the

diminution of length of circuit, and by the increase of the sum of the sections of the tubes, so that we may take as the section of the chimney that indicated in (59).

65. *Chimneys common to several Furnaces.*—In most large factories there is only one chimney for all the furnaces. Two advantages are derived from this arrangement—1, a saving in the cost of construction; 2, uniformity of draught, which does not exist in a chimney communicating with only one furnace. The saving is obvious, for one chimney costs less to build than several, supposing the section of the single chimney equal to the sum of the sections of the others. With regard to the second advantage, it must be remarked that, in a furnace having a special chimney, the draught is very variable; it is small immediately after the fire is made up, and increases in proportion as combustion becomes more active. It is diminished in a high degree by opening the furnace-doors. But if several furnaces communicate with a common chimney, and care be taken to make up the fires successively, a mean draught will exist in the chimney, which will increase in regularity with the number of the furnaces.

A common chimney has usually a section equal to the sum of the sections of the partial chimneys that would correspond with each furnace. The section thus obtained is certainly too great, because the resistance is much smaller than the sum of the resistances in the partial chimneys which it replaces. But this excess of draught, which may be modified at will, offers no inconvenience.

66. *Chimneys in which the Smoke, or the Gases soluble in Water, are precipitated or absorbed by Injections of Water.*—It has been proposed to precipitate the smoke and to dissolve the soluble gases, which, in certain circumstances, are found mingled with the gases from the furnace, by dropping water under the form of very fine rain into horizontal pipes traversed by the gases before reaching the chimney; but the gases being almost completely cooled, it became necessary to reheat them to produce the draught.

Hedley, an ironmaster at Newcastle-on-Tyne, invented the plan of making the smoke pass through a series of vertical pipes, ascending and descending, and into each of the pipes in which the smoke descended he dropped a small quantity of water. In spite of the cooling caused thereby, the draught was very strong, even in pipes of 3 or 4 mètres in height. By this means, all the matters carried off by the gases may be stopped, and especially the soot which floats upon the heated air. This arrangement has been successfully applied to a locomotive of the Sunderland and Durham Railway. Although this mode of condensation has long been known, it has never been generally adopted, because it is complicated and necessitates a certain amount of labour to raise the water required for the purpose of condensation, and because this water, if not clean, would often be a source of embarrassment. But this arrangement would possess great advantages when in the gases which escape from the furnace there are, independently of those involved by combustion, noisome gases and vapours, such as those evolved in the manufacture of soda, or solid matters carried off by the current and which it is profitable to arrest, as in the case of lead or zinc works.

67. *Draught Chimneys.*—All chimneys are, strictly speaking, draught chimneys; but we denote in a more special manner by this name chimneys constructed for the purpose of rendering certain situations wholesome by ventilation. In these, the phenomena that happen are much more simple than in factory chimneys. Indeed, the air drawn through them, being usually only slightly heated, is not all found to pass through the furnace-grating, which occupies only a small portion of the section of the chimney. Sometimes even the furnace is placed laterally, so that the section of the chimney is not sensibly changed in the vicinity of the grating; the resistance of the latter may, in this case, be wholly neglected, and the results of calculation are then very accurate. When a grating is wholly covered with fuel, and the whole of the air drawn by the chimney is forced to pass through it, if there is no appreciable loss of heat by radiation, the temperature of the air beyond the grating is about 1200°, and the volume of air drawn per kilogramme of coal is 18 cubic mètres. For draught chimneys, on the contrary, the air is rarely heated above 20°; the heat which it absorbs the cubic mètre is $1^{k} \cdot 3 \times 20 \times 0 \cdot 25 = 6 \cdot 5$, and, consequently, the volume of air drawn by 1 kilogramme of coal is $8000 \div 6 \cdot 5 = 1230$ cubic mètres.

68. To begin with the simplest case, let us consider a draught chimney of a height H and a diameter D, communicating in its lower portion with a cylindrical channel of a length $l$ and a diameter $d$ smaller than D; denoting the temperatures of the air in the chimney and the air in the channel or pipe by $t$ and $\theta$, the negative pressure at the bottom of the chimney will be $\mathrm{H}\,a\,(t-\theta) + 1\,a\,t$; denoting it by P, and calling $p$ the force corresponding to the effective velocity, we shall have $\mathrm{P} - p = \frac{\mathrm{K}\,l}{d}p + \frac{\mathrm{K}\,\mathrm{H}}{\mathrm{D}} \cdot \frac{d^4}{\mathrm{D}^4}p + p + (\mathrm{A} - \mathrm{B})p$. The first two terms of the second equation represent the resistance occasioned by friction in the pipe and in the chimney; the third, the loss of force due to the sudden change of direction; the last, the loss of force at the entrance of the pipe and the increase of force at the entrance of the chimney. But in general the conducting-pipes are long enough to render their resistance very great relatively to the value of A − B. Thus the second member of the equation may be reduced to the first three terms, which gives as the rate of ingress,

$$v = \sqrt{\frac{2\,g\,\mathrm{H}\,a\,(t-\theta)}{1+a\,t}} \sqrt{\frac{1}{\frac{\mathrm{K}\,l}{d} + \frac{\mathrm{K}\,\mathrm{H}}{\mathrm{D}} \cdot \frac{d^4}{\mathrm{D}^4} + 2}}. \qquad [1]$$

69. Suppose, for example, a square chimney communicating with a pipe having also a square section; taking $\mathrm{H} = 30$ mètres, $\mathrm{D} = 1$ mètre, $d = 0^{m} \cdot 5$, $l = 500$ mètres, $\theta = 15°$, $t = 35°$, the formula becomes

$$v = \sqrt{\frac{19 \cdot 62 \times 30 \times 0 \cdot 00366 \times 20}{1 + 0 \cdot 00366 \times 35}} \sqrt{\frac{1}{21 + 0 \cdot 72 + 2}} = 6 \cdot 18 \times 0 \cdot 193 = 1^{m} \cdot 19.$$

The section of the pipe being 0·25 square mètre, the volume of air drawn per second will be $1·19 \times 0·25 = 0·297$ cubic mètre; the expenditure of heat will be about $1069 \times 1^{k}·3 \times 20 \times 0·24 = 6670$ an hour, a quantity of heat only slightly less than that produced by the combustion of 1 kilogramme of coal.

70. Let us now consider the most general case. Suppose a chimney, still prismatic, communicating with a pipe turning in all directions, the several parts of which are at different temperatures. The variations of temperature will act in two ways: 1st, by modifying the force which occasions the flow; 2nd, by causing variations of velocity, and, consequently, variations in the resistance due to friction. But, as the influence of the variations of temperature upon the velocity, and, consequently, upon the friction is very small, we may suppose that the velocity varies only inversely as the sections. Then, denoting the force and the total sum of the resistances by P and R, the velocity of flow will be given by the formula $v = \sqrt{\frac{2gP}{1 \times R}}$.

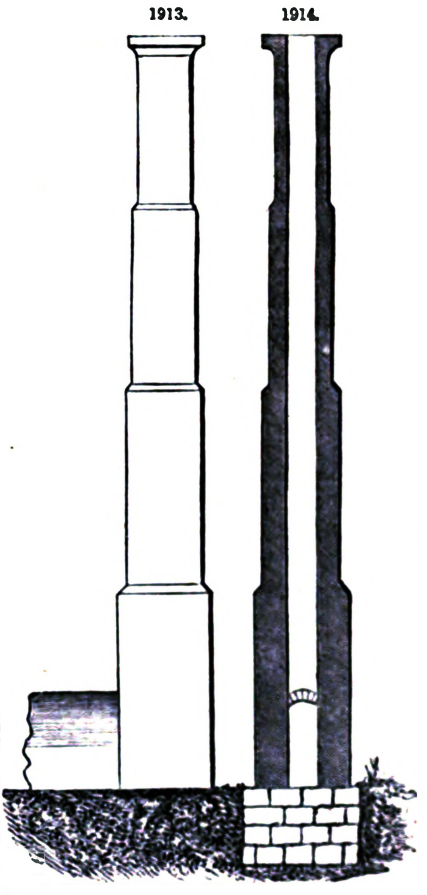
The value of R may be found by the methods indicated when treating of the flow of compressed gases.

71. *Construction of Chimneys.*—As the height and the section of chimneys may be determined by the preceding considerations, we have now only to examine the nature of the materials, the thickness, and the general arrangements to be adopted.

72. *Factory Chimneys.*—Factory chimneys always stand alone; they are constructed of bricks or of iron, and with either of these materials they produce the same effects, because the cooling which the air undergoes in iron chimneys has no appreciable influence upon the draught (57).

73. The best form of section, from the point of view of diminishing the resistance, is that which, for a given surface, has the least perimeter or circumference. This is, of course, the circular form, and next the polygonal with a large number of sides. Iron chimneys have always the circular form. In brick chimneys, the section is circular, square, or octagonal. Round chimneys are generally preferred; they require, for an equal section, less material.

74. Let us now examine the form of the vertical section passing through the axis. When chimneys are of small height, they are made prismatic internally, and the walls have a greater thickness at the base than at the summit, Figs. 1913, 1914. But when they are of great height, they have always the form of the pyramid inside and outside, Figs. 1915, 1916, to increase the base on which they stand, while reducing, as much as possible, the cube of the masonry. It is impossible to calculate the interior and exterior diminution of section, because the calculation would depend upon too large a number of unknown elements. We shall confine ourselves to giving that which has been found sufficient in practice.




75. In large factory chimneys, the internal diminution, a lineal mètre, is about $0^{m}·012$ to $0^{m}·018$; and the external diminution varies from 0·025 to 0·035. The thickness of the masonry at the top is from 0·11 to 0·22, the breadth or length of an ordinary brick. Thus, if we denote the interior diameter at the top of a chimney by $d$, its exterior diameter by $d'$, and the interior and exterior diameters at the bottom of the chimney by D and D', we shall have $d' = d + 0·22$, or $d' = d + 0·44$, $D = d = 2Hm$, $D' = d' + 2Hm'$, $m$ being included between 0·012 and 0·018, and $m'$ between 0·025 and 0·035.

Suppose, for example, a chimney of 20 mètres in height and 0·60 in interior diameter at the top; the interior diameter D at the bottom will be, taking $m = 0·014$, $1^{m}·16$; the exterior diameter $d'$ at the top will be $0·60 + 0·22 = 0·82$; and the exterior diameter D' at the bottom, taking $m = 0·03$, will be $2^{m}·02$.

The chimney of the tobacco manufactory at Paris, which is constructed to burn 700 kilogrammes of coal an hour, which corresponds to more than 150 horse-power, is 29 mètres in height; internally it is $1^{m}·03$ in diameter at the top, $2^{m}·15$ at the base; and externally, at the top, $1^{m}·30$, and at the base $3^{m}·45$. The diminution is, in this case, both externally and internally, too great.

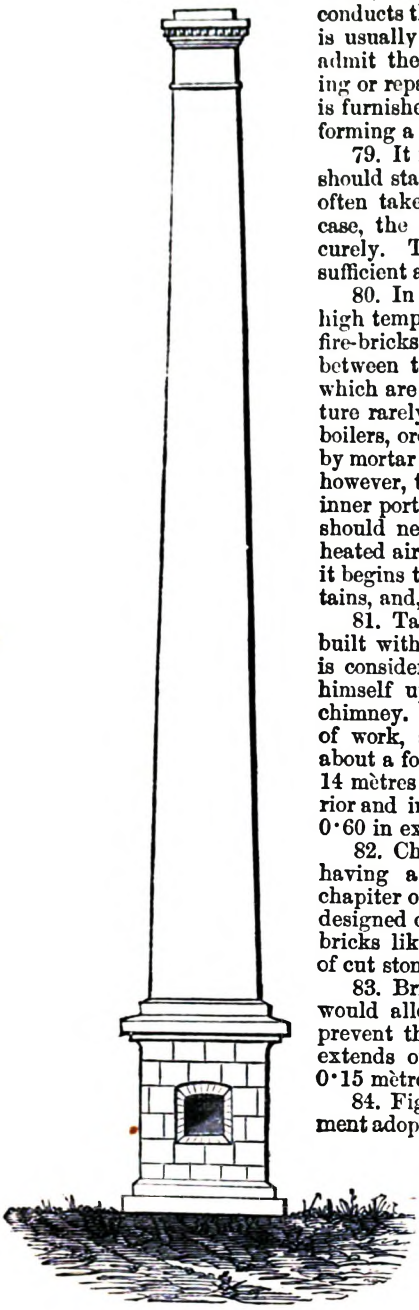
76. If it were required to construct conical surfaces internally and externally, the execution of the work would be rather difficult, and we should be obliged to cut a large number of the bricks, which would entail considerable expense; besides, bricks do not resist so well when they are broken as when they are whole, because their external crust has much greater tenacity than their inner portions.

Conical or prismatic chimneys may be constructed by a series of cylinders or prisms, which would occasion sudden retreats, both on the inside and on the outside; but the arrangement shown

in Fig. 1916 is generally preferred. The chimney is conical or pyramidal on the outside, and the thickness of the masonry varies by sudden leaps on the inside; the retreats occur every 11 centi mètres, the breadth of a brick.

77. Brick chimneys are usually from 20 to 30 mètres in height; sometimes, but rarely, 40 mètres. M. Grouvelle mentions a chimney at Manchester that is 125 mètres in height, 7·50 in exterior diameter at the base, and 2·70 at the top; 4,000,000 bricks were employed in its construction.

1915.



78. Brick chimneys are usually placed upon prismatic socles, pierced on opposite sides with two apertures; one is designed to receive the channel which conducts the smoke to the chimney; the other, which is usually closed up by a thin brick wall, serves to admit the workman when the chimney needs sweeping or repairs. To facilitate this labour, the chimney is furnished with horizontal bars placed $0^{m}\cdot50$ apart, forming a kind of ladder.

79. It is of the highest importance that a chimney should stand upon a firm foundation, for the sinking often takes place unequally; and, when this is the case, the chimney either falls, or stands very insecurely. This is a point to which builders do not pay sufficient attention.

80. In chimneys intended to receive air at a very high temperature, as those of reverberatory furnaces, fire-bricks must be employed, and the interstices between them filled with brick clay. In chimneys which are intended to receive vapours at a temperature rarely exceeding 300°, as in the case of steam-boilers, ordinary bricks may be used, bound together by mortar containing siliceous sand; it would be well, however, to employ fire-bricks for the casing of the inner portion at the bottom of the chimney. Plaster should never be used when the temperature of the heated air exceeds 100°, because at this temperature it begins to lose the hygrometric water which it contains, and, consequently, its tenacity.

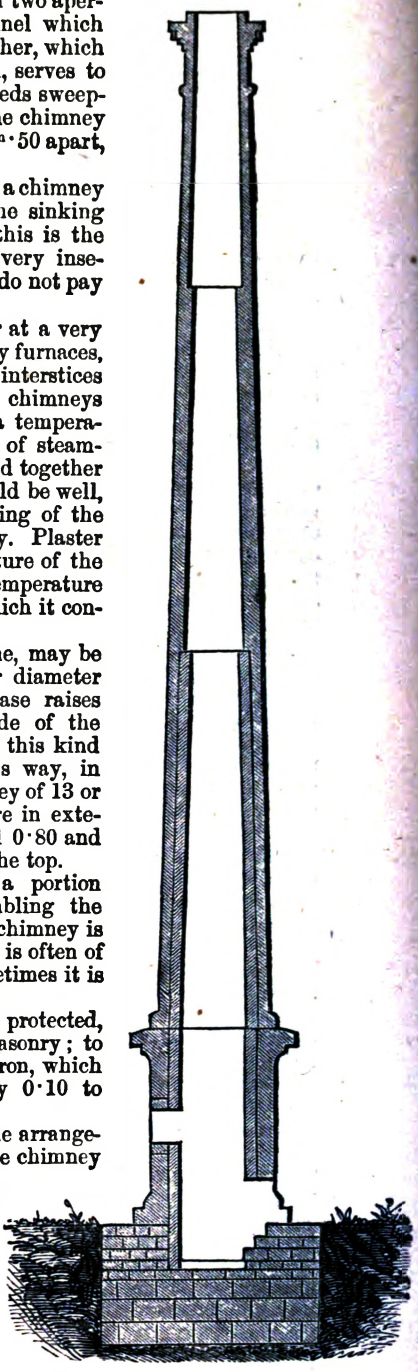
81. Tall chimneys, when standing alone, may be built without exterior scaffolding, if their diameter is considerable; the workman in this case raises himself upon supports fixed on the inside of the chimney. A good workman accustomed to this kind of work, assisted by a boy, may, in this way, in about a fortnight, raise a pyramidal chimney of 13 or 14 mètres in height, 2 mètres and 1 mètre in exterior and interior diameter at the base, and 0·80 and 0·60 in exterior and interior diameter at the top.

82. Chimneys usually terminate in a portion having a greater diameter, and resembling the chapiter of a column; this portion of the chimney is designed only as ornament. The chapter is often of bricks like the rest of the chimney; sometimes it is of cut stone.

83. Brick chapiters, if they were not protected, would allow the rain to penetrate the masonry; to prevent this they are covered with plate iron, which extends over the outside and inside by 0·10 to 0·15 mètre.

84. Fig. 1917 represents a section of the arrangement adopted for large iron chimneys. The chimney itself is bolted to an iron socle or base, fixed upon a mass of masonry by four stout bolts passing through the masonry. When these chimneys are very high, they are tied externally to the ground or to some neighbouring buildings. To prevent the rusting of the metal, the chimney is covered with coal-tar, which will bear a high temperature without alteration.

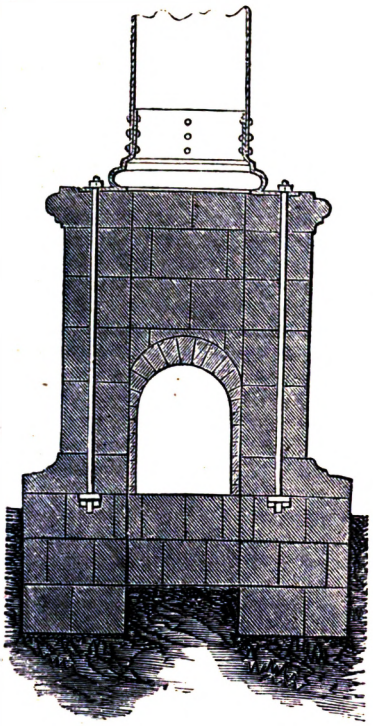
1916.



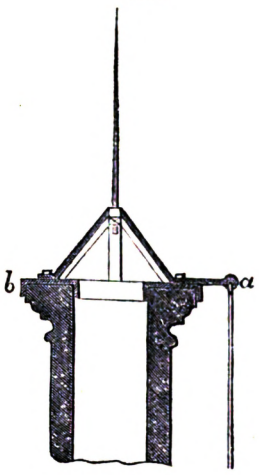
85. Tall factory chimneys attract the lightning, both by their great height and by the great conducting power of the soot which covers their inner surface; it is, therefore, necessary to protect them by means of a conductor. Figs. 1918 and 1919 show the usual arrangements in such cases. In the first, four rods, riveted to the iron plate at the top of the chimney, support the conductor; one of the rods is produced horizontally and fixed at its extremity to the conducting-wire. The second represents a lightning conductor upon an iron chimney. The conductor is supported by

three rods riveted to the edge of the chimney, which serves instead of a conducting-wire, and the chain which establishes communication with the ground is fixed to its lower portion.

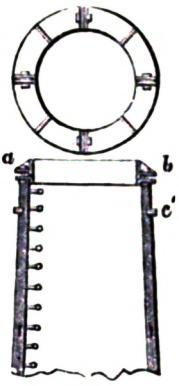
1917.



1918.

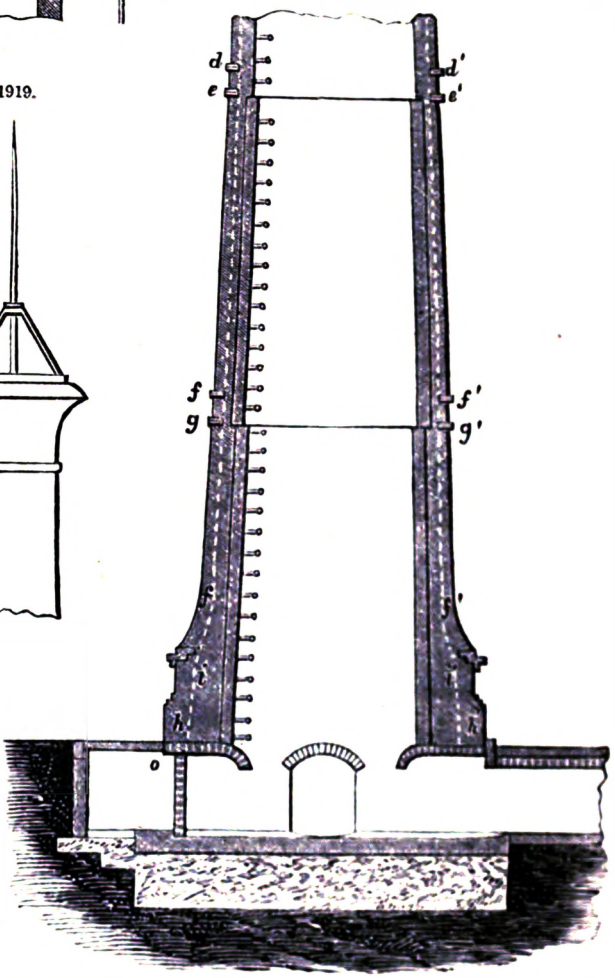



1921.

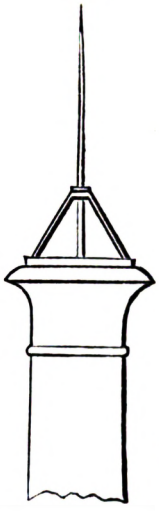



1922.

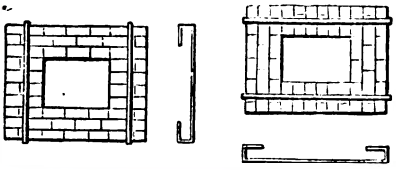
1923.




1919.



1920.



86. When single chimneys are very high, and are designed to receive air at a high temperature, it is necessary to strengthen them. We see an instance of this strengthening in the square section chimneys of puddling furnaces. When chimneys are conical, iron hoops are built into the masonry.

In the rectangular chimneys of steam-boilers, flat iron bars having a kind of hook at each end of sufficient dimensions to take in two or three rows of bricks are built into the masonry in alternate directions, as shown in Fig. 1920.

87. Figs. 1921 to 1923 represent a large factory chimney of a circular section, built according to the plans of MM. Thomas and Laurens. This chimney is 40 mètres in height; the diameter is at the base 3·35 and at the top 2$^{m}$·02; therefore the diminution of section is on the inside 0·016 a mètre: the exterior diameter at the base is 5·65, and at the top 2·52; consequently the external diminution is 0·030 a mètre. The chimney is formed of five cylinders having each a height of about 8 mètres, and conical both on the inside and on the outside. The thickness of the masonry is 3 bricks for the first portion, and is successively reduced to 2½ bricks, 2 bricks, 1½ and 1, for the other portions. Thirty-eight iron hoops $h\,h'$, $i\,i'$, are built into the

masonry. The first portion of the chimney has an inner casing of fire-bricks. The top is covered with an iron plate *a b*, composed of four pieces bolted together.

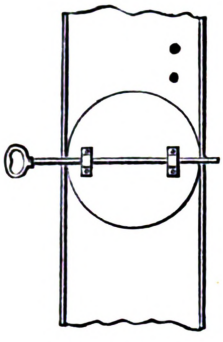
The engineers above alluded to, often place in their chimneys at the points *c c'*, *d d'*, *e e'*, *f f*, *g g'*, the base of each of the cylinders, bands of coloured bricks; and the spaces between those bands are filled with bricks of several colours, worked into various patterns for ornamental purposes.

88. *Registers.*—In every heating apparatus, whatever its dimensions and purpose may be, it is requisite to place, either at the top or at the bottom of the chimney, an iron plate, by means of which the draught may be diminished, and the chimney closed entirely during the suspension of work in the furnace. Registers are of great service in apparatuses which are only occasionally in operation, because, the current of air being intercepted, the furnace cools very slowly.

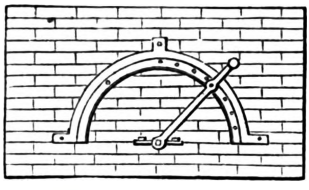
89. They may be arranged in a great variety of ways. In apparatuses of small dimensions, having iron chimneys, the opening in the chimney is regulated by a disc, Fig. 1924, turning about an axis traversing the opposite sides of the pipe, and worked from the outside.

90. This arrangement might with equal advantage be adopted for larger chimneys; but as the friction of the axis in its bearings would not alone be sufficient to keep the disc in its position, we should have to affix to it, on the outside of the chimney, a rod or handle perpendicular to its direction, by which it might be fixed as shown in Fig. 1925. The disc should be of cast iron, as wrought iron is more liable to rust, and should have considerable thickness to prevent warping. When the air-channel is horizontal, the arrangement shown in Fig. 1926 may be adopted. The register, in this case, is a cast-iron plate *b*, turning about an axis upon a pivot *c*, and which is moved in an iron frame by means of a crank *a*.

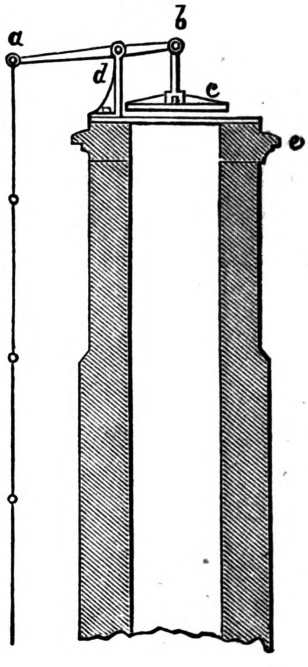
1924.



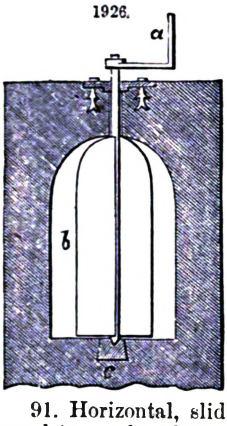
1925.



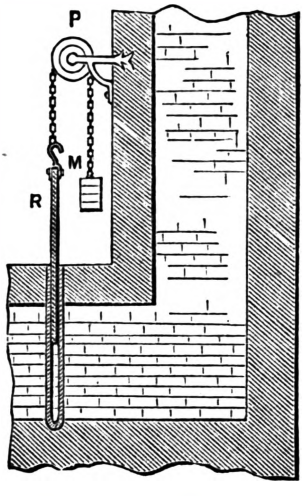
1928.




1926.




1927.




91. Horizontal, sliding trap-doors are sometimes employed; but in large chimneys it is more usual to employ those which move vertically, and which are held by a counterpoise. Fig. 1927 is a section of this arrangement through the length of the air-channel. R is a cast-iron plate sliding in grooves, also of cast iron, fixed in the masonry. It is held by a chain which passes over a pulley P, and is attached to a weight M.

92. This last arrangement is the one generally adopted; it has, however, one great objection, namely, a considerable space between the edges of the plate and the grooves of the iron frame in which it moves; this allows a rush of cold air into the chimney, whereby the draught is considerably diminished in the furnace. This rush of cold air may be prevented when the register is lowered by constructing it with projecting arms at the top, made to fall into a groove filled with sand.

93. When the temperature of the heated air exceeds 500° or 600°, the contrivances which we have been considering cannot be employed, because the iron would be quickly warped or rusted. The best method of regulating the draught of a chimney in such cases, is to place the register at the top of the chimney, where the disc, or plate, being always exposed on one side to the air, becomes heated in a very much smaller degree. This arrangement is shown in Fig. 1928; *c* is a cast-iron disc affixed to a vertical rod, connected by a joint to the end of the lever *a b* turning about the point *d*; a chain *g* is attached to the extremity *a*, by means of which the distance of the disc from the top of the chimney is regulated. This arrangement has the disadvantage of requiring a workman to ascend to the top of the chimney when the apparatus is got out of order.

See ANEMOMETER. BAROMETER. BOILER. FUEL. PYROMETER. THERMOMETER. VENTILATION.

CHISEL. FR., *Ciseau, Burin*; GER., *Meissel*; ITAL., *Scarpello*; SPAN., *Escoplo.*

See HAND-TOOLS.

CHOCOLATE MACHINE. FR., *Moulin à chocolat*; GER., *Chocoladenmühle*; ITAL., *Macchina da cioccolata*; SPAN., *Molino de chocolate.*

See MILLS.

CHRONOGRAPH. FR., *Chronograph*; GER., *Kronograph*; ITAL., *Cronografo.*

See GUNPOWDER.

CHUCK. FR., *Mandrin*; GER., *Futter, Patrone*; ITAL., *Coppaia.*

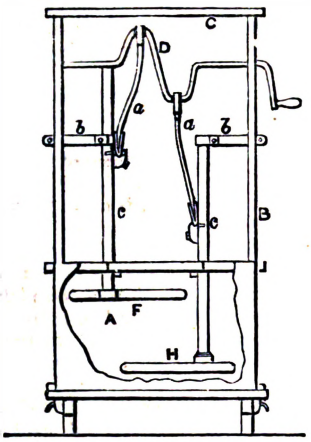
A chuck is contrived to fit the mandrel of a turning-lathe, and to hold the material to be turned.

See LATHES.

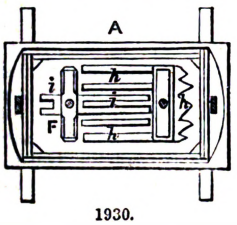
CHURN. FR., *Baratte*; GER., *Butterfass*; ITAL., *Zangola*; SPAN., *Mantequera.*

L. Bacon's churn, Figs. 1929, 1930, has two reciprocating dashers F, H, with fingers *h h*, *i i*, these dashers being worked by a double-throw crank D. The dasher-rods *c c* have two guides *b b*, one through the cover of the churn and the other through the upper end; and connecting-rods *a*, *a*, attach the dasher-rods to the crank. The machine is enclosed in the case A, C, B.

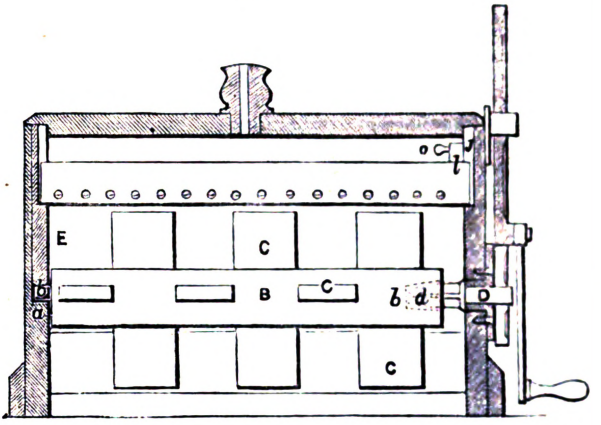
1929.

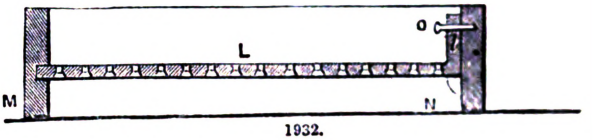



1930.




1931.




1932.

In J. Harrison Doolittle's churn, Figs. 1931, 1932, the dasher B *b* C is turned by a driving journal D *d*. The dasher is removable, and when replaced in the churn rests in the grooved recess *a*, where it is secured by a tapering dove-tail key E.

A movable horizontal brake L *l*, Fig. 1932, resting in a cavity M and on a ledge N, thoroughly agitates the cream, the brake being fastened with the pin O.

CIDER MILL. FR., *Moulin à pommes*; GER., *Apfelpresse*; ITAL., *Torchio da sidro*; SPAN., *Molino y prensa para hacer sidra.*

See MILLS.

CIRCULAR SAW. FR., *Scie circulaire*; GER., *Kreissage*; ITAL., *Sega circolare*; SPAN., *Sierra circular.*

See SAWS.

CIRCUMFERENTER. FR., *Graphomètre*; GER., *Graphometer*; ITAL., *Grafometro a bussola*; SPAN., *Grafómetro.*

See SURVEYING.

CLACK-VALVE. FR., *Soupape à charnière*; GER., *Ventilklappe*; ITAL., *Valvola a ganghero*; SPAN., *Válvula de cuero.*

See PUMPS.

CLAMP. FR., *Emboîture*; GER., *Hirnleiste*; ITAL., *Tuirluppo*; SPAN., *Cepo.*

See MECHANICAL MOVEMENTS.

CLEAT. FR., *Taquet*; GER., *Klampe*; ITAL., *Rinforzo.*

A cleat is a narrow strip of wood or of metal, fixed to something for the purpose of affording strength or of securing a piece of work in its proper position.

CLIP-DRUM. FR., *Tambour à tenailles*; GER., *Scherentrommel.*

See BRAKE, pp. 586 and 619. MECHANICAL MOVEMENTS.

CLOTH-WORKING MACHINERY. FR., *Machine à faire les draps*; GER., *Tuchmaschine*; ITAL., *Macchina da panni*; SPAN., *Maquinaria para fabricar paños.*

See CALENDER.

CLUTCH. Fr., *Clef d'arrêt*; Ger., *Ausrück Kuppelung*; Ital., *Connessione a denti.*

A clutch is a projecting tooth or piece of machinery for connecting shafts with each other or with wheels so as to be disengaged at pleasure. See Gearing.

COAL-CUTTING MACHINE. Fr., *Machine à tailler des houilles*; Ger., *Kohlenbreck Maschine*; Ital., *Macchina da spezzare litantrace*; Span., *Máquina para cortar carbon de piedra.*

The objects, says John Fernie, of Leeds, to be gained by the application of machinery to coal cutting are, firstly, the cheapening of the work; secondly, the saving of a large quantity of coal, which, in the ordinary process of holing or undergoing by hand labour with the pick, is broken up into slack and dust; thirdly, the removal of the danger attendant upon undergoing by hand labour; fourthly, the getting of a larger quantity of coal out of the pit with the same length of working faces opened; and fifthly, in the case of machines worked by compressed air, the collateral advantage of better ventilation and a cooler atmosphere in the mine, owing to the discharge of the compressed air after each stroke of the tool. The difficulties attending the application of machinery to work previously performed by hand are greatly increased in the case of coal-cutting machines, by their having to work at great depths below ground, and in the very confined passages of a mine.

Fernie, in the 'Institute of M. E.,' described two coal-cutting machines driven by compressed air, one having a pick worked by a bell-crank lever, with an action like that of the ordinary pick used in hand work, and the other working a straight-action tool somewhat in the manner of a horizontal traversing slotting machine. Both these machines had been successfully employed in regular work for a length of time at collieries in the neighbourhood of Leeds.

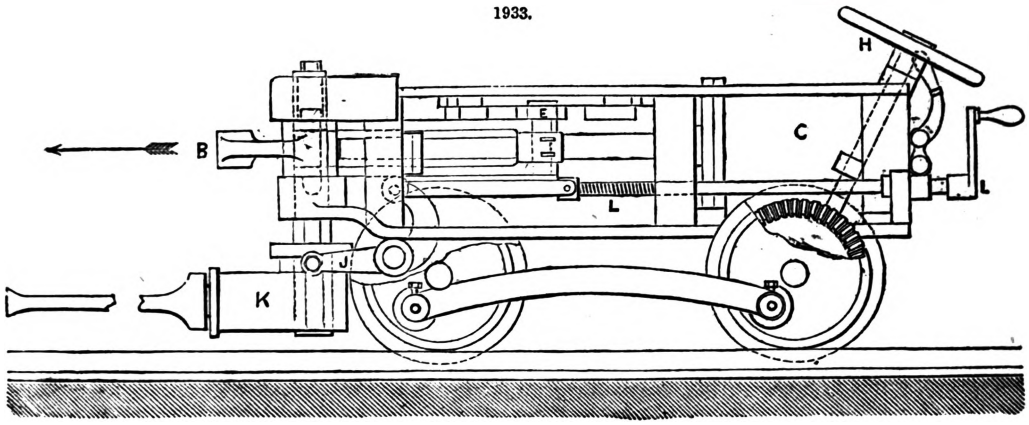
The coal-cutting machine of W. and S. Frith, shown in Figs. 1933 to 1935, is constructed for working a pick by means of a bell-crank lever, so as to give an action similar to that of the ordinary pick employed in hand work.

The pick A is fixed in a socket in one of the arms of the bell-crank lever B, the other arm of which is worked direct by the piston-rod of the horizontal cylinder C. The slide-valve D, Fig. 1936, for the admission and discharge of the compressed air by which the machine is driven, is an ordinary slide, worked by a tappet-roller E upon the piston-rod; the machine is thus self-acting as regards the strokes of the pick, which is started to work as soon as the compressed air is turned on by the stop-cock F in the supply-pipe G. The machine is mounted upon four wheels running upon the ordinary rails of the colliery, and is advanced the requisite distance between each blow of the pick by a hand-wheel H connected by gearing with the hind pair of carrying-wheels. The two pairs of wheels are coupled together, in order to render the full adhesion available for the forward motion of the machine; and by this means it is found that sufficient adhesion is obtained without the necessity of laying down a special rack-rail for the feed motion.

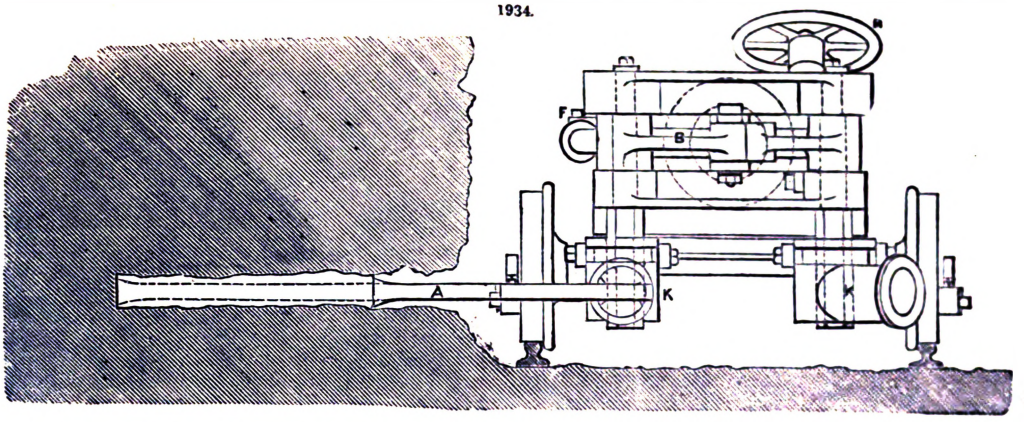
As the return of the pick after each blow is made by means of the self-acting tappet-motion working the slide-valve, it is necessary that the tool should go to the full extent of its stroke at each blow, before it can be withdrawn again. The amount of feed between each blow has therefore to be regulated by the attendant, according to the hardness of the seam of coal in which the machine is cutting, so that the pick shall complete an entire cut at each blow. In the event, however, of the pick being advanced too far at any blow, so as to put too much work upon it and stop it before the stroke is completed, it is only necessary to draw the machine back again by means of the hand-wheel H, until the pick is released from the cut; the unfinished stroke is then completed, and the pick goes on working again the same as before the stoppage. In order to allow of altering the height at which the pick performs the holing in the coal, the socket K carrying the pick is made to slide vertically upon the shaft of the bell-crank lever B, the height of the socket being adjusted by the forked arm J controlled by the screwed rod and handle L.

One of these pick machines worked the whole of the undercutting in the West Yorkshire Coal and Iron Co.'s Colliery at Tingley, near Leeds, holing a seam of coal 3 ft. 8 in. thick; and the compressed air for driving it was supplied by an air-compressing engine at the surface, with steam-cylinder of 20 in. diameter and 3 ft. stroke, working an air-cylinder of 18 in. diameter and the same stroke, and compressing the air to about 50 lbs. the square in. pressure. The depth of the pit is 170 yds., and the air is conveyed down the shaft and along the mine in 2½-in. cast-iron pipes, with a 1¼-in. wrought-iron pipe laid up the bords to the working faces, and then a 1¼-in. flexible tube to the coal-cutting machine. Small air-vessels are placed at intervals of 500 yds. along the air-main,

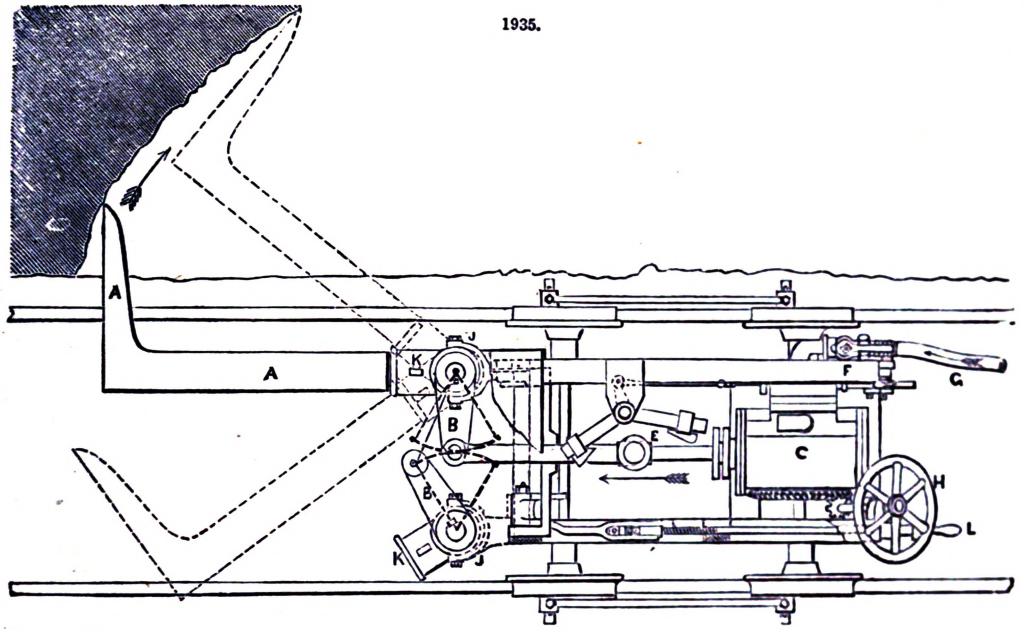
1933.



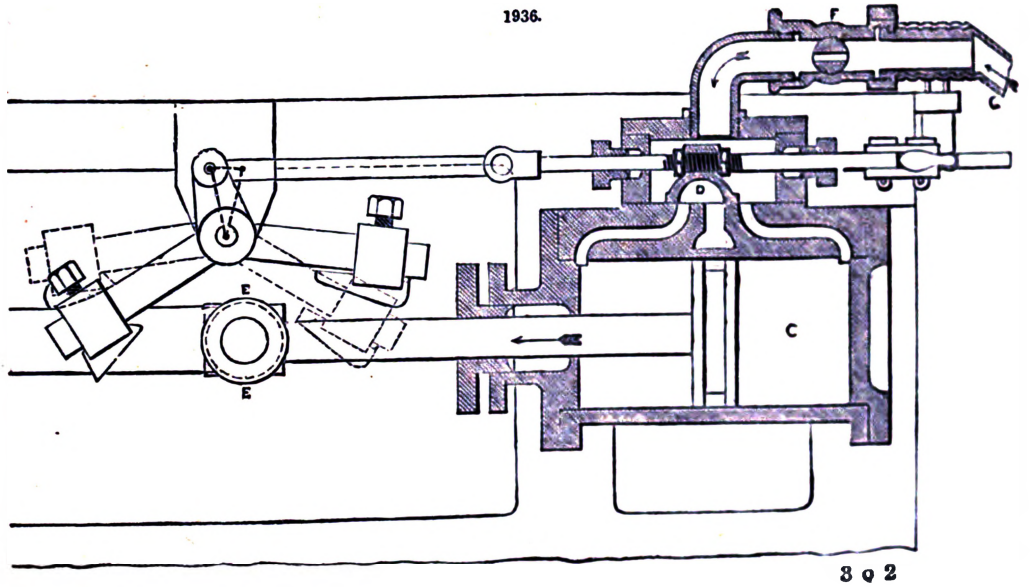
1934.




1935.



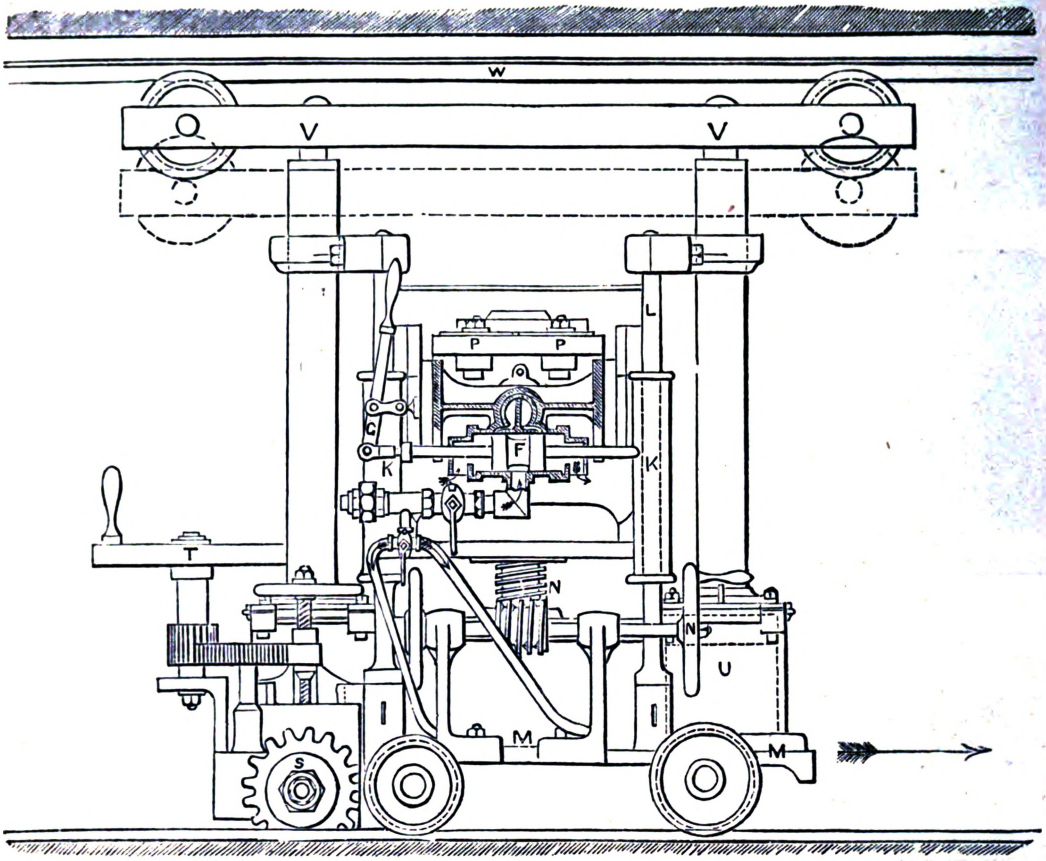

1936.



for the purpose of maintaining the pressure of the air at the machine when working at a considerable distance in the mine: the machine is worked at a distance of as much as a mile from the shaft.

In a trial of this machine, it was found that a pick of 75 lbs. weight, cutting a groove to a depth of 24 in. in from the face, gave about 74 blows a minute. At the colliery the coal was got by the long-wall system of working, as shown in Fig. 1937, in which the machine is indicated at M working along the straight face of 50 yds. at one of the banks. The time occupied by the machine in

1937.




undercutting a length of 56 ft. was twenty-five minutes, including all stoppages for clearing the rubbish out of the hole and for backing the machine when the pick occasionally made an incomplete stroke. The machine was then run back to the starting-point, and set to work again with a longer pick of 90 lbs. weight, completing the previous cut to the final depth of 3 ft. 9 in. from the face. With this pick the blows were about sixty a minute, and the half-length of 28 ft. was undercut in seventeen minutes, including all stoppages. The time occupied in running the machine back and changing the pick was sixteen minutes. The machine in this case was working at a distance of about a mile from the bottom of the shaft.

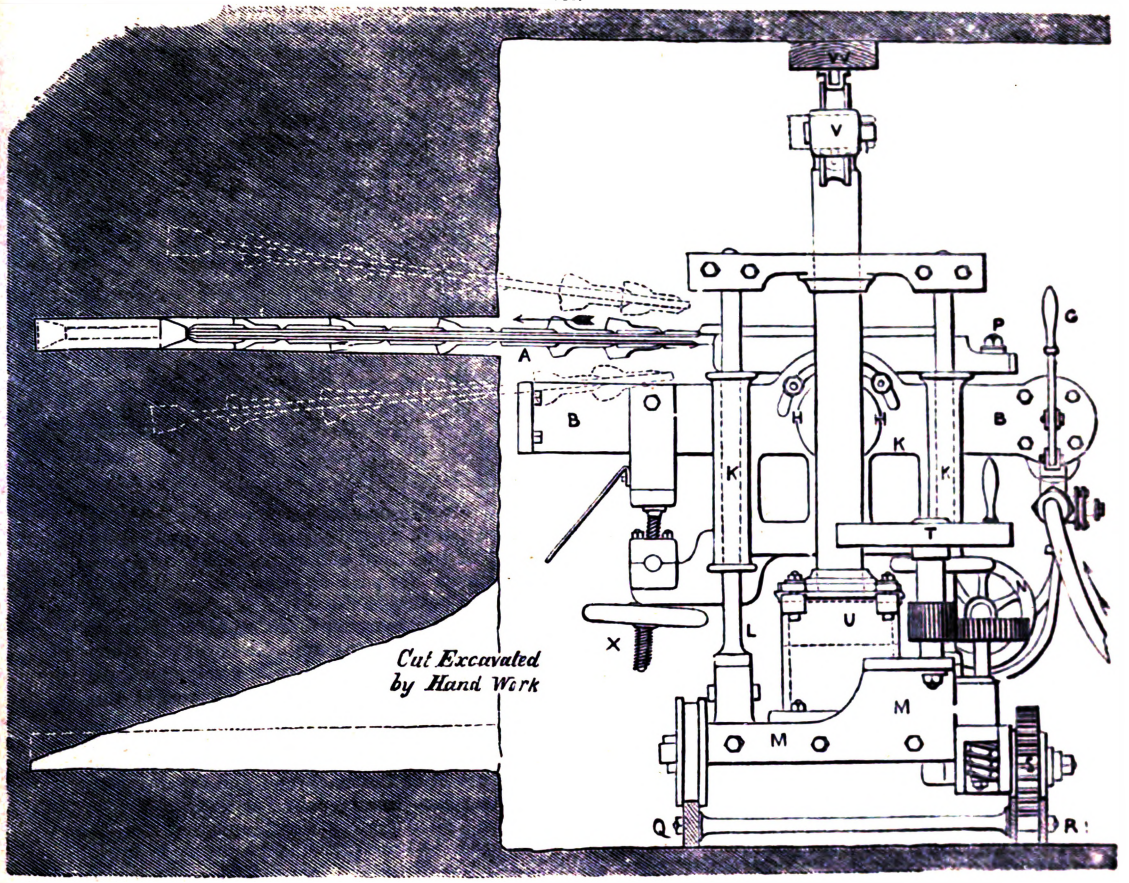
From this trial it appears that in undercutting to the depth of 24 in. in a single course, the work done by the machine was at the rate of about 30 square yds. an hour; and in undercutting in two courses to the total depth of 3 ft. 9 in., the work was done at the mean rate of about 15 square yds. an hour, including the time required for running the machine back and changing the pick.

The width or height of the groove cut out by the pick is 2 in. at the inner extremity, widening out slightly towards the face of the coal. It is necessary to stop the machine at intervals, in order to clear out the rubbish left in the hole; and the rails in front of the machine have also to be cleared of the material thrown out by each return stroke of the pick. Two men are required to attend to the machine, one working the hand-wheel for the advance of the machine, and the other clearing away the stuff.

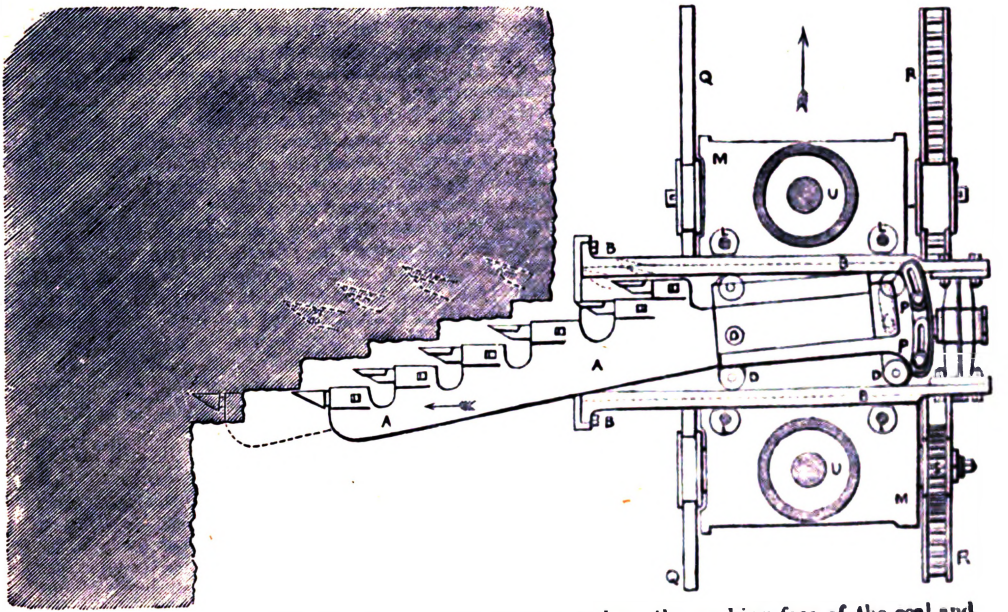
A good criterion of the actual rate of working that may be safely reckoned upon with this machine in regular practice is afforded by its performance upon an occasion when it was kept continuously at work for twenty-four hours consecutively, on 21st and 22nd of May, 1868. During this time the machine was employed upon five different banks of coal successively, requiring accordingly to be shifted four times for the purpose. The average depth of holing was 3 ft. 6 in., and the total length of work completed to that depth during the twenty-four hours amounted to 257 yds. This gives the practical rate of holing by the machine at rather more than 12 square yds. an hour, including all stoppages for clearing the pick in working and for shifting the machine on the completion of each separate length of bank.

The other coal-cutting machine, before alluded to, shown in Figs. 1937 to 1939, is the invention of G. E. Donisthorpe, and may be described as a horizontal traversing slotting machine, the

1938.



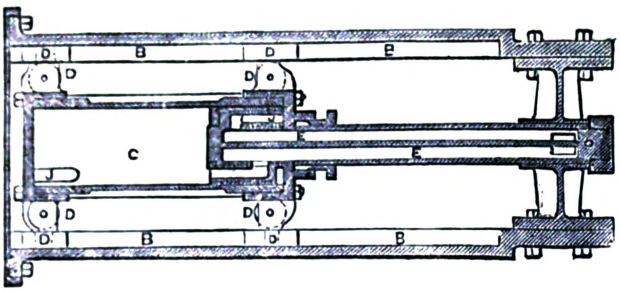

1939.




work remaining stationary, while the machine traverses along the working face of the coal and cuts out a horizontal slot or groove along the bottom of the seam of coal or along a parting in the thickness of the seam itself.

The cutter-bar A carrying the cutting tools is fixed upon the upper side of the working cylinder C, which moves horizontally forwards and backwards at each stroke, the piston and piston-rod remaining stationary. This arrangement has the advantage of economizing space, and giving greater stiffness and a better attachment of the cutter-bar; and the whole is guided steadily between the guides B B by means of four sets of steel rollers D D attached to the cylinder and steadying it both vertically and laterally, as shown in the sectional plan of the cylinder, Fig. 1940. The piston-rod E is made hollow, as shown in Figs. 1940 and 1942, having two passages

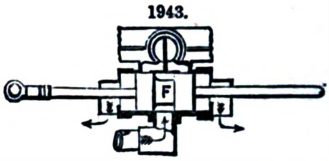
1940.




1941.

1942.

1943.




communicating with the opposite sides of the piston; and the alternate admission and exhaustion of the compressed air is regulated by a cylindrical slide-valve F, Figs. 1937 and 1943, worked by the hand-lever G. The ports in the piston are circular, and at each end of the cylinder a projecting plug J is fixed on the inside of the cover, opposite to the port, as shown in Figs. 1940, 1941; this plug entering the port at the end of the stroke prevents the complete escape of the whole of the air in exhausting; and the air thus retained in the cylinder forms an air-cushion at the end of the stroke, whereby the piston is prevented from striking the cylinder-cover at either end. A subsidiary port I, Fig. 1841, alongside the main port, and provided with a valve opening outwards, affords a passage for the admission of the compressed air at the commencement of the next stroke, until the main port is unstopped by the withdrawal of the plug J.

The working cylinder C is 6 in. diameter with 12 in. stroke; and the frame B in which it is carried is itself slung upon horizontal trunnions H, Fig. 1938, in another frame K sliding vertically upon the pillars L L, which are fixed on the base-plate M of the machine; and by means of a screw N and worm-wheel, Fig. 1937, the working cylinder can thus be raised or lowered bodily to any height at which the cutter is required to work. The trunnions and the curved slot H, Fig. 1938, also allow of the cutter being adjusted by means of the hand-wheel and screw X to work at an inclination to the horizontal, between the limits shown by the two dotted positions in Fig. 1938.

The cutter-bar A, Figs. 1938, 1939, is of cast steel, having six sockets for carrying the cutting tools. The tools are made of flat bar steel, with one-quarter twist in the shank, by which means the cuttings are thrown away from the face of the cut at each stroke of the bar A. The cutters are placed about 7 in. apart longitudinally along the length of the bar A, the average depth of the cut being about 3 ft. 4 in. in from the face of the coal; and the length of stroke being 12 in., the tool does no work during the first 5 inches of the stroke, but acquires a rapid motion whereby it strikes upon the coal with the percussive action of a blow, instead of cutting by a uniform steady pressure like an ordinary slotting tool. Previous to the adoption of this principle of working, the present pressure of air of 60 to 70 lbs. a square inch was found insufficient to work the machine; but with the percussive action now obtained this pressure is found completely effective, and the diameter of the working cylinder being 6 in., the blow is given with a total force of 1700 lbs. or ¾ ton upon the tool. The cutters are stepped 2½ in. successively in advance of one another, as shown in the plan, Fig. 1939; and the bar is fixed upon the working cylinder by a centre pin O and set-screws P P, allowing it to be set obliquely in plan at an inclination to the line of the stroke, as shown by the dotted lines in Fig. 1939. By this arrangement the inclination of the cutters to the work can be slightly increased or diminished, according as may be required by the quality of the coal, so as to obtain under all circumstances the most effective action of the cutters. The width of their cutting edges ranges from 1⅝ in. in the cutter at the outer extremity of the bar to 3 in. in the cutter nearest the working cylinder; and the slot cut out by the machine is therefore of the slightly tapered form shown in Fig. 1938.

The machine is mounted on four double-flanged wheels, Fig. 1939, running on rails laid for the purpose. The rail on one side is a plain wrought-iron bar Q placed on edge; and the other rail R is made of two bars placed 2 in. apart, with a series of cross-pins at 1½ in. pitch, forming an open rack-rail, into which gears a pinion S worked by a hand-wheel T, whereby the machine is advanced for each cut, the ordinary amount of feed being 1¼ in. a cut. As the advance is given by hand by the man working the machine, any number of strokes can be given by the tool before the machine is moved forwards, in case the coal is too hard for the cutters to accomplish the full depth of cut at a single blow. The traversing pinion S gearing into the rack-rail is mounted in a slide on the base-plate M of the machine, whereby it can be raised out of gear with the rack when the machine has to be drawn away from one part of the mine to another.

The pressure of the air working the machine is also employed for steadying it against the

blows of the tool, so as to ensure the full effect of the blow being expended upon the coal at each stroke; otherwise the tool would be liable to be bent or broken, and the work would be irregular. This is accomplished by means of two vertical cylinders U U, each 8½ in. diameter, the piston-rods of which stand up towards the roof of the mine, and are connected together at the top by a horizontal frame V carrying a grooved wheel at each end. A loose iron rail on a wood batten W is placed above the grooved wheels; and the compressed air being admitted on the under-side of the pistons in the cylinders U, the rail is pressed up against the roof of the mine, as shown in Figs. 1937, 1938. The total pressure exerted by the pair of cylinders U U amounts to 6800 lbs., or upwards of 3 tons, which is found amply sufficient to resist the blow of the tool. When the machine in its forward traverse has arrived at the end of the roof-rail W, the pressure is shut off from the cylinders U, and the air is let out from them through cocks opened by hand, thus lowering the frame V as shown by the dotted lines in Fig. 1937; the roof-rail is then shifted forwards to the extent of its length, and the pressure being readmitted to the cylinders U, the machine is again ready for continuing its forward traverse as before. The pressure exerted against the roof being elastic allows the top rail to accommodate itself to any irregularities in the level of the roof.

In working this coal-cutting machine at the West Riding Colliery of Pope and Pearson, at Normanton, it was observed that the number of strokes made by the tool was from 75 to 80 a minute, the pressure of air at the machine being from 65 to 70 lbs. a square inch at the time. The average depth of the cut during the time of observation was about 2 ft. 9 in., as there was a clearance space of more than 1 ft. left between the side of the machine and the face of the coal, the rails not having been laid close enough to the face of the coal. The width of the cut was about 2 in. at the inner end, widening to about 3 in. at the face of the coal; and as the cut was in this case being made in a parting of dirt of about the same thickness, no waste of coal was produced by cutting the groove. One man is required to work the machine, working the air-valve F by the hand-lever G, Fig. 1937, and also giving the feed of the tool by the hand-wheel T advancing the machine; and from three to five strokes were given by the tool between each advance of the machine, for completing the cut to the full depth of the groove; about three turns were then given to the traversing hand-wheel, advancing the machine about 1¼ in., after which the same number of strokes were again given with the tool. The cuttings are cleared out of the groove by a man following the machine with a narrow curved rake; and the height of the cutting tool in the machine is regulated occasionally, according to the slight variations in the level of the parting in which the groove is made, so as to keep the tool always working in the parting.

The width of the groove cut by this machine is shown in Fig. 1938, the width at the face of the coal being not more than about 3¼ in. in holing to the full depth to which the machine can work. In undergoing by hand to the same depth, the size of the cut is as shown in Fig. 1938, having a width of at least 13 in. at the face of the coal, making the whole size of the cut about three times that of the narrow groove excavated by the machine, which is shown by the dotted line in Fig. 1938. Supposing the machine to be holing in the solid coal, the waste produced by the undergoing in a seam of 5 ft. thickness, such as is being worked at the West Riding Colliery, would amount to only about 4 per cent., as compared with about 12 per cent. waste with hand work. An estimate of the absolute quantity of waste made by hand work in good seams of coal amounts to as much as 12 per cent., the whole of which is rendered nearly worthless; and taking the whole quantity of coal raised per annum in this country at 100,000,000 tons, the waste produced in undergoing by hand labour amounts consequently to as much as 14,000,000 tons a year.

The compressed air for working the machine is supplied by an air-compressing pump of 18 in. diameter and 2 ft. 10 in. stroke, worked by an engine that is employed for winding coals up an incline at the bottom of the pit. The compressed air is delivered by the pump into a large air-vessel, 3 ft. diameter and 30 ft. long, from which it is conveyed along the mine by a wrought-iron pipe 2½ in. diameter and ¼ in. thick, put together with ordinary screwed sockets, and terminating in a portion of 1¼-in. pipe and a long length of flexible tubing of the same size, which is coiled on the floor and drawn out by the machine as it advances along the face of the coal. Great difficulty was originally experienced in maintaining the pressure of the air at the machine when working at considerable distances from the compressing pump; but this has been completely obviated by the introduction of a second smaller air-vessel at the working face where the machine is in operation. This smaller air-vessel is 2 ft. diameter and 6 ft. long, and is mounted on wheels for the convenience of being quickly removed to any part of the mine. The air-compressing pump is capable of supplying air enough for working three of the coal-cutting machines.

By the adoption of compressed air as the medium for transmitting the power to work these coal-cutting machines, the important collateral advantage is obtained of improved ventilation at the working faces. The discharge of the exhaust air from the machines delivers a supply of fresh air, free from noxious gas, during the whole time that the machine is working; and the coldness of the discharged air, consequent upon its expansion at the moment of liberation, has a highly beneficial effect in reducing the temperature at the working faces. During the trial made by Fernie at the Tingley Colliery, a shot was fired at a short distance from the machine, for breaking down a mass of coal; and although the smoke at first completely obscured the working face and the machine, the whole of it was cleared away in so short a time as two minutes, having been carried off by the current of exhaust air discharged from the machine. In the case of any danger arising from accumulation of gas in the goaf or elsewhere, the means of safety is at hand, as it is only necessary to detach the india-rubber supply-pipe from the machine, and discharge a continuous jet of fresh air in the required direction, whereby the gas is speedily dispersed, and the dangerous place rendered safe. Also, as the undercutting of the coal is done so much quicker by the machines than by hand labour, the employment of the machines requires a smaller extent of working faces to be kept open for getting the same quantity of coal in the same time; the air has therefore a shorter distance to travel and becomes le loaded with gas, and is consequently safer and more wholesome for the colliers.

In reference to the greater quantity of coal that is got by the use of the machine from a given length of working face in a given time, the quantity got by one man in a day, including undercutting, breaking down, and filling the coal, is 3 tons when undercutting by hand labour, assuming a yield of 1 ton a cubic yard; and taking a working face of 48 yds. length, the four men working on that length of face would therefore get 96 tons in eight days. The machine, however, will undercut 96 yds. in one day, and this quantity would then be broken down and filled in by four men in two days, making only three days for getting the 96 tons with the machine, in comparison with the eight days required for hand labour. Hence, with the machine, as much coal can be got from 18 yds. length of face as from 48 yds. by hand in the same time.

In regard to the danger to which the collier is exposed in holing by hand labour, from the risk of the coal falling down and crushing him while lying with his body inserted partly within the groove which he is excavating, it is evident that this danger is entirely removed by the employment of a machine for performing the holing, as the men are altogether clear of the working face, and the tool alone enters the groove in process of excavation.

*Hydraulic Coal-cutting Machine, employed at Kippax Colliery, near Leeds.*—This machine, Figs. 1944 to 1948, is intended to take the place of manual labour in *nicking*, or *kirving*, or, as it is called in Yorkshire, *baring* the coal. The seam of coal worked at Kippax Colliery is the well-known Haigh Moor seam.

Its depth from the surface is 120 yds., and its section is as follows:—

| | Ft. | In. |
|---|---|---|
| Coal .. .. .. .. .. .. .. .. .. | 3 | 8 |
| Band of hard shale, with pyrites .. .. .. | 0 | 2 |
| Coal .. .. .. .. .. .. .. .. .. | 1 | 8 |
| Total thickness .. .. .. | 5 | 6 |

The roof is soft shale, containing thin beds of coal. In the Kippax and surrounding districts this coal is worked in its entire thickness, the band of shale having thinned out to 2 in., as above mentioned; but at Horbury, three miles west of Wakefield, the Haigh Moor is worked in two distinct beds, the upper and lower divisions being at that place 12 or 13 yds. apart.

T. W. Embleton, speaking in 1865, observed that "the band at Kippax was the only part of the seam that was removed by this self-acting coal-cutting machine. The direction of the workings was towards the rise of the coal, or north end, as it is locally called."

While the machine proceeds with the baring, completing the work at once going over it, square pieces of wood and wedges are inserted loosely into the baring, at intervals of 4 or 5 ft., to keep the coal in position till the colliers come to remove it. This slight support, however, does not prevent the coal so bared from detaching itself from the unbared part of the bed. The line of fracture was, in the case referred to, a few inches beyond the extremity or back of the baring, and in one even straight line.

The quantity of coal obtained for every yard of face was 2 tons, and the yield of small coal produced by breaking up the detached coal and the bottom coal was about 8 per cent.

The lower division of the coal was blasted with gunpowder in the usual way.

Water was the medium employed to actuate this coal-cutting machine, and water being for all practical purposes incompressible, its full power, diminished only by the friction of its passage through the pipes, can, therefore, be transmitted and applied at any distance from its source.

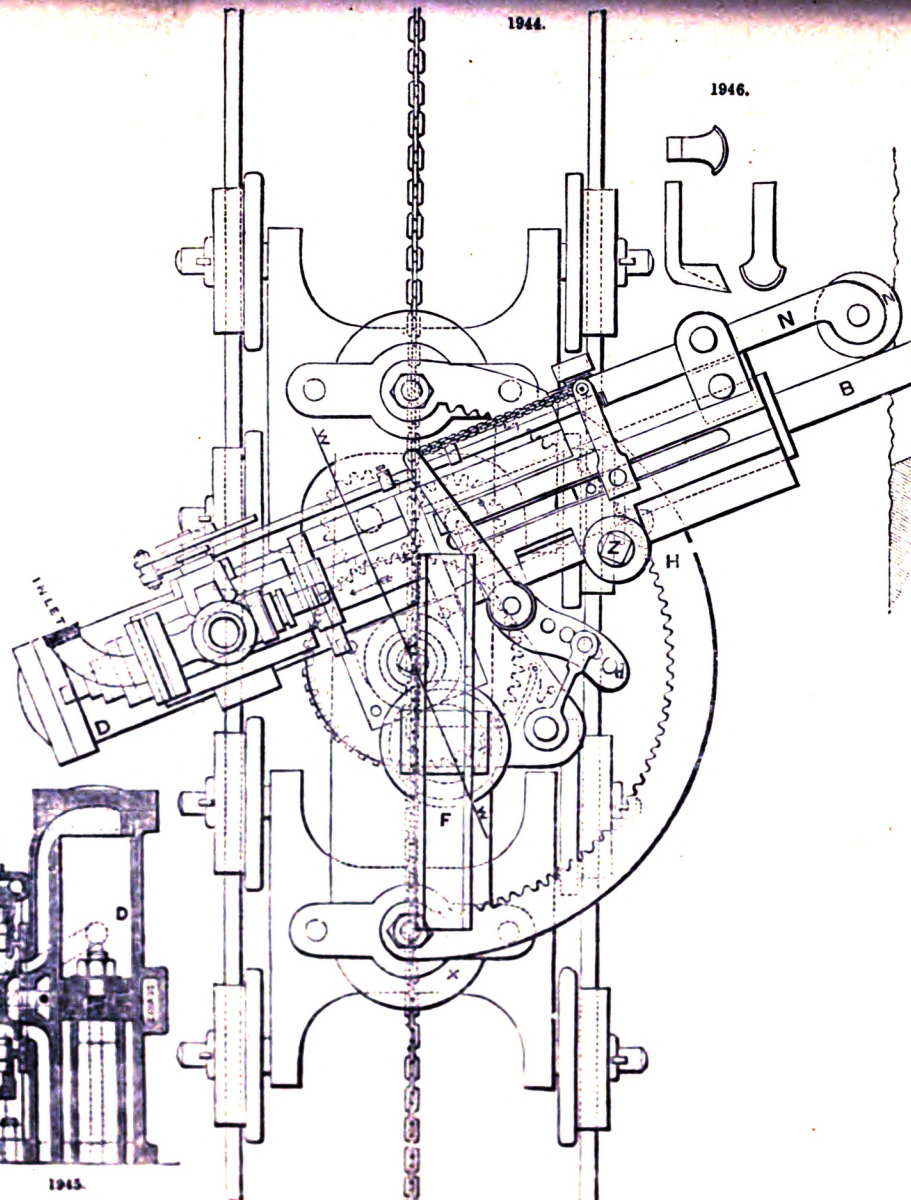
This self-acting machine consists of a hydraulic reciprocating engine, having a cylinder of 4½ in. diameter and 18 in. stroke, working horizontally, or at any angle to suit the inclination of the coal, or at any required height above the floor. The piston-rod is a hollow trunk or ram, into which is fitted a cutter-bar easily removed, carrying three or more cutting tools. The cutting tools can be adjusted so as to enter the coal at any angle with the line of the face. The position of the cutting tools will be most readily understood by reference to Fig. 1944. Although the length of the stroke of each of the cutting tools is 18 in., the practical cutting length of the stroke into the coal is about 16 in., and, consequently, the three cutters jointly give a total depth of 4 ft. at each stroke. The cutting cylinder has a valve-motion, which is self-acting; and the length of stroke of the tools can be varied, or any number of strokes can be given at any part of the entire length of the stroke. The cutting action of the tools being a steady push or thrust without any percussion, it is necessary that the machine should be firmly held upon the rails during the cutting stroke, and be released so as to traverse forward at the end of the return or back stroke, and this rigid fixing of the machine upon the rails is effected by means of a vertical self-acting holder-on, which is a prolongation of the piston-rod of another cylinder, mounted upon and becoming part of the machine itself, Fig. 1948.

The piston of this cylinder is actuated by means of the same self-acting valve-motion as that of the cutting cylinder, and the holder-on is retained in its dead-fast position by means of a small keep-valve, which retains the water during the cutting stroke. At the return or back stroke the valve-motion opens the keep-valve and releases the water, thus enabling the holder-on F to descend and to slacken its pressure against the roof, and thus the machine is free to traverse upon the rails the requisite distance for the next cut. This traversing or progressive motion is also self-acting. For this purpose a chain is made fast ahead, close upon the floor, and passes over a grooved pulley on the machine, which gets the necessary bite upon the chain. This pulley makes part of a revolution, to suit any length of traverse, at the moment when the cutter-bar is completing its back-stroke.

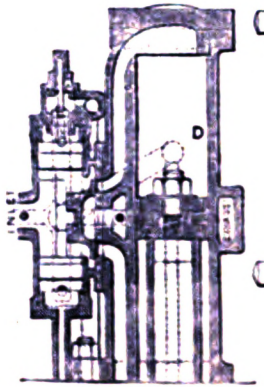
The amount of feed or distance of cut is easily adjusted, and the self-acting traversing power is sufficient to move the machine upon skids, where they are found to be more convenient than wheels.

Unless the cutting tools complete a full stroke, the traverse-motion does not come into operation, but the tool will continue to cut in the same place until the full stroke is completed, and then

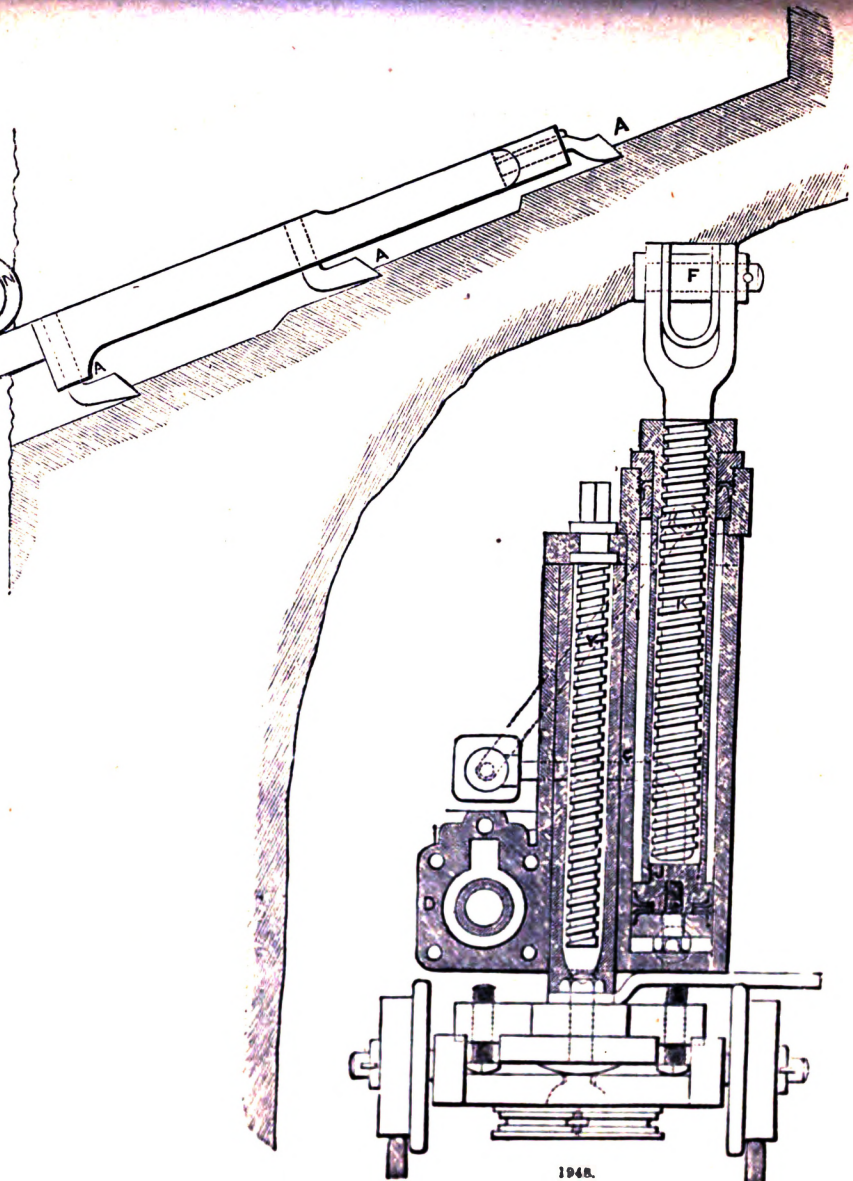
1944.




1945.




1946.




1948.

only will the traverse-motion come into action; thus the back of the baring is always parallel with the rail upon which the machine travels, thereby causing the coal to break off in one uniform line.

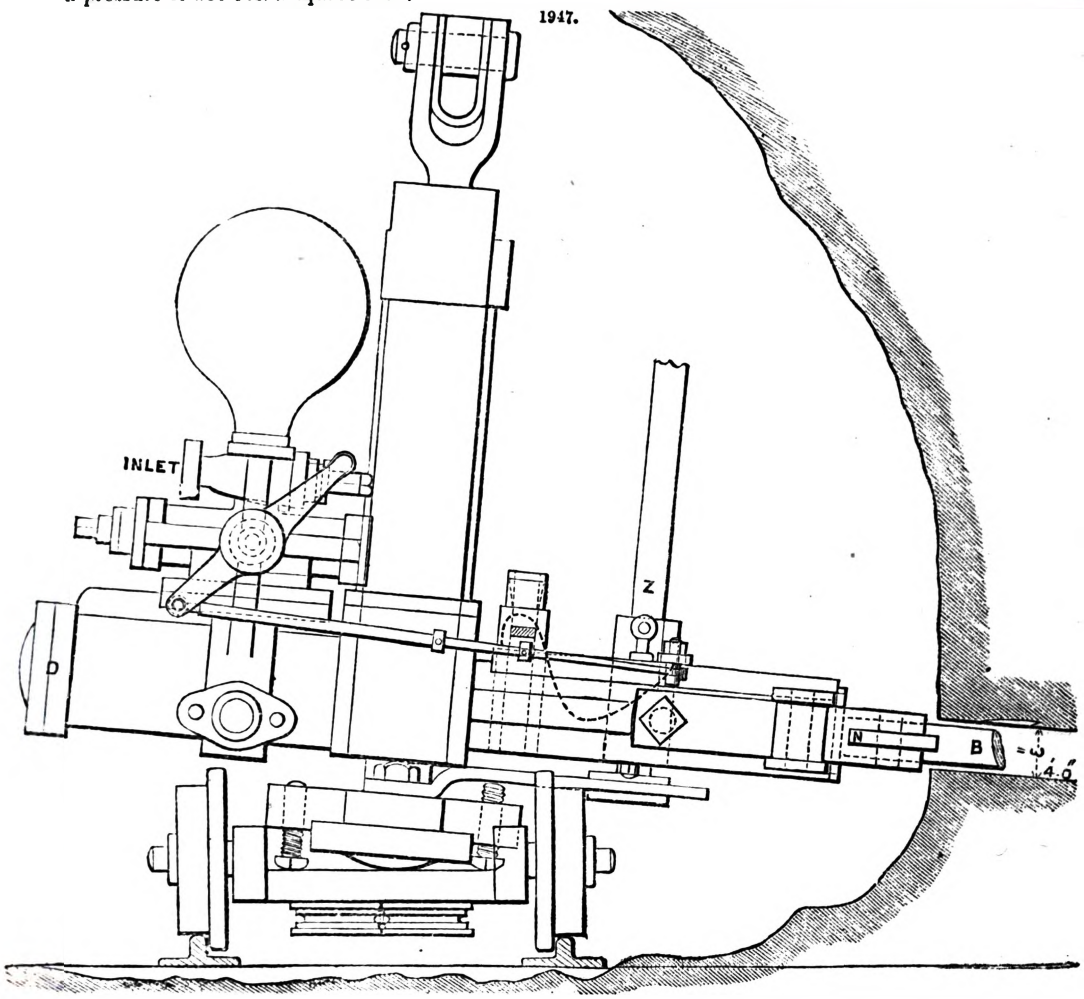
The cutting tools, Fig. 1946, are of a form easy of construction, and are very strong, and capable of penetrating hard material with little risk of breaking. The cutting edge is nearly a ¼ in. thick, and any or all of the cutters can be removed and replaced in a few moments.

The machine can be adapted to any gauge in use for the roads of the mine, and is easily moved from place to place on its four wheels. The supplementary wheels at each end are used only when in operation, in order to secure a greater base.

The water pressure by which the machine is actuated is produced, in this instance, by an engine placed at the bottom of the shaft.

The cylinder of this engine is 14 in. diameter; stroke, 2 ft. 3 in. Attached to the engine are two double-action pumps of 4½ in. diameter, and 12 in. stroke. These are capable of maintaining a pressure of 360 lbs. a square inch.

1947.




When the machine is not working, the engine regulates its own speed accordingly, and is further used for forcing water out of the mine to the surface. When convenient, the water pressure may be obtained from any pumping engine on the mine, by connecting the supply-pipes with the ordinary pumps, thus obviating any special outlay of capital for the moving power. The machine when working makes 25 strokes per minute, and uses 40 gallons of water.

The water is conveyed from the engine to the machine chiefly by 2-in. wrought-iron pipes, the remainder being 1½-in. bore. The total length of these pipes is about 600 yds.

To allow the machine to traverse on the rails, it is connected to the 1½-in. pipes by means of an india-rubber tube of the same diameter. This tube will bear a pressure of 500 lbs. to the square inch. The wrought-iron pipes are the ordinary butt-welded steam-tubes, tested to a pressure of 500 lbs. to the square inch. They are used in preference to cast-iron pipes, because they occupy little space, are easily screwed together and bent, and will accommodate themselves readily to the varying floor of the mine, with no risk of breakage or leakage.

The exhausted or waste water is conveyed away from the machine by 2½-in. india-rubber hose, and by 2-in. ordinary gas-tubes, to the place whence it was forced, and thus a very small quantity of water is required to work the machine, namely, as much as is necessary to fill the circuit of the pipes. The water may be used over and over again as in the ordinary hydraulic press.

The pressure at the engine is 80 lbs. in excess of that at the machine when working at 20 strokes per minute. Whenever the cutting tools meet with any extra resistance, the retarded speed allows this pressure to equalize itself, and thus overcome any obstacle.

The amount of pressure used for working the machine varies from 150 lbs. to 300 lbs. an inch, according to the hardness of the material to be cut.

Fig. 1944 is a ground plan when in working position, angle and height adjustable. F holder-on or feeder, *l* traverse chain. D, self-acting valve-motion. X Z H, self-acting traverse movement. N, guide-bar and roller. A A A, total depth cut at each stroke; stroke of each cutting tool 1 ft. 6 in.; total stroke 4 ft. B, stem of cutters.

Fig. 1946, details of cutters.

D C, Fig. 1945, section through valve-chest.

D K, Fig. 1948, sectional end view taken through W W, Fig. 1944. Y, elevating screw.

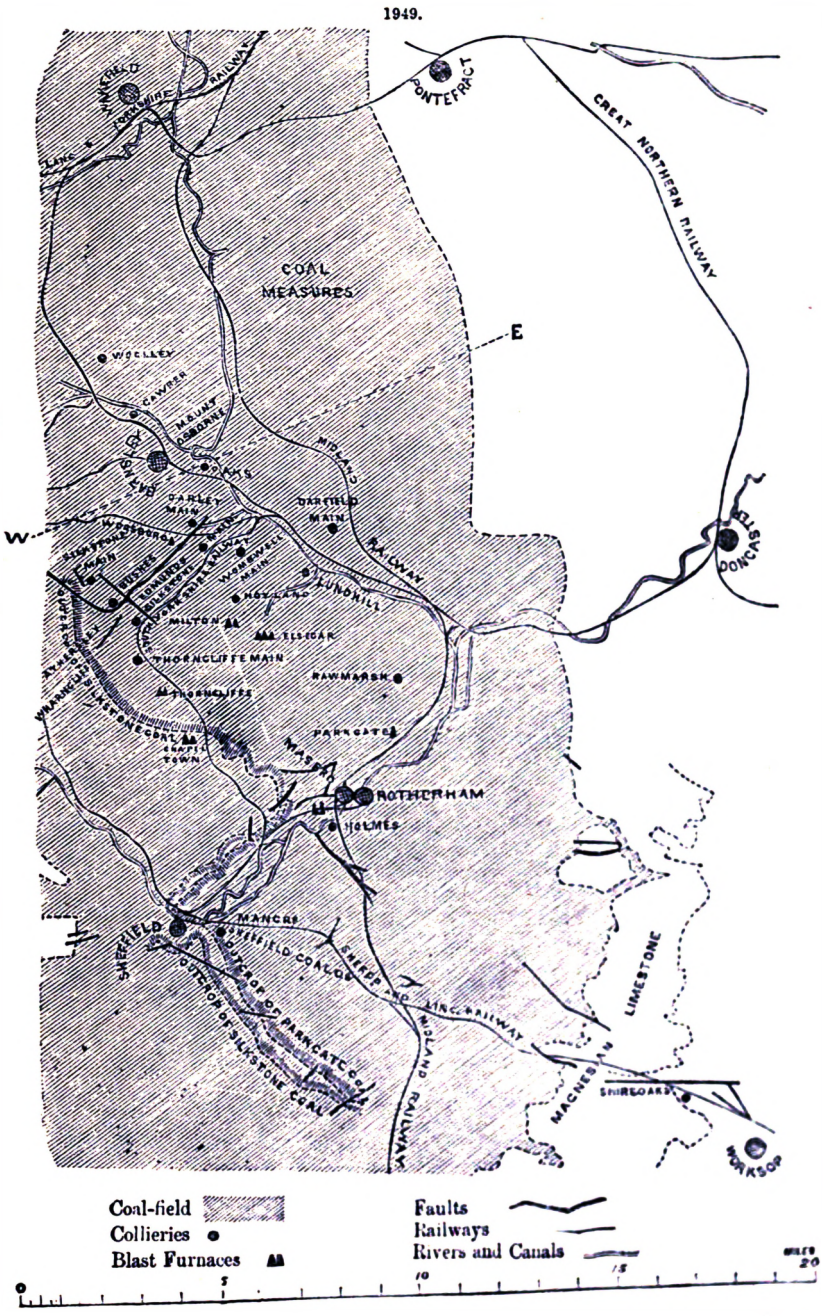
Fig. 1947, end view in working condition, cutting at an angle.

COAL MINING. Fr., *Exploitation de houillère;* Ger., *Berybau;* Ital., *Arte del cavatore di litantrace;* Span., *Extraccion de carbon de piedra.*

Parkin Jeffcock, in a paper published in the 'Proceedings of the Inst. of M. E.,' 1862, ably examined this subject, and applied his reasoning to the general features of the South Yorkshire district with reference to the circumstances affecting mining engineering.

The accompanying general plan, Fig. 1949, given by Jeffcock, represents that portion of the

1949.



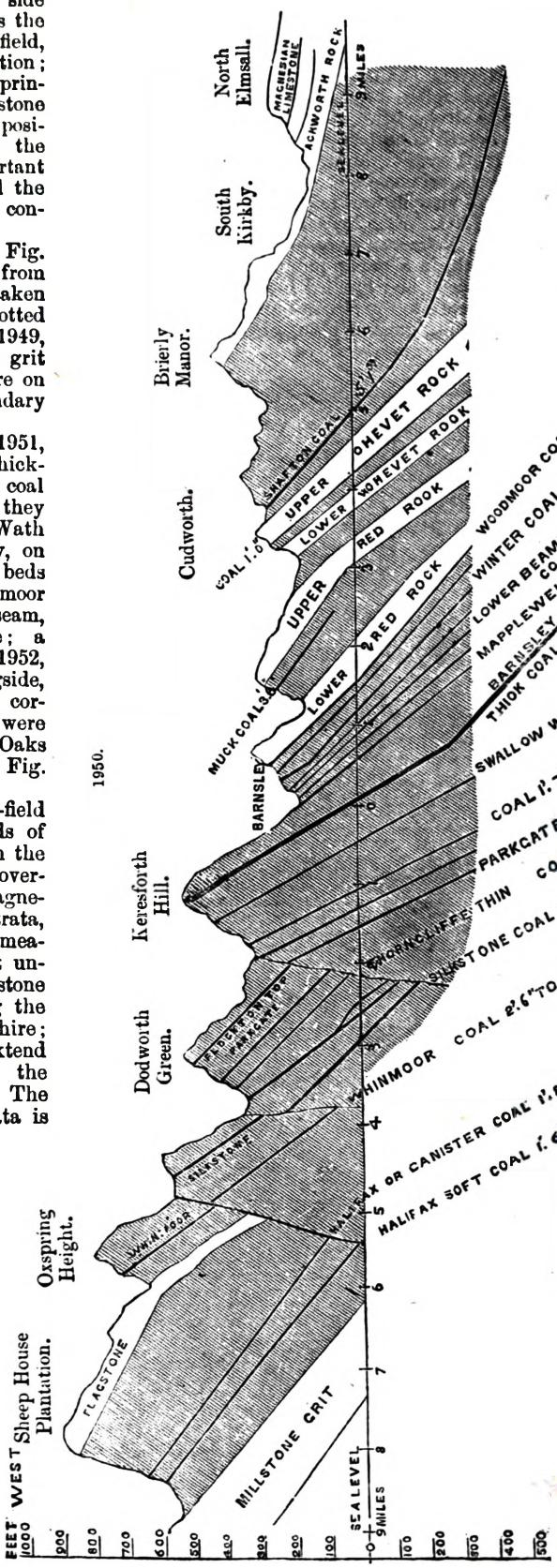
Yorkshire coal-field which is more particularly called the South Yorkshire district; extending from Sheffield on the south to Wakefield on the north about 25 miles, and from west to east about 20 miles altogether, on either side of Barnsley. The plan shows the general extent of the coal-field, indicated by the shaded portion; the outcrops of two of the principal seams of coal, the Silkstone and the Parkgate seams; the positions of the principal faults; the localities of the more important collieries and iron-works; and the lines of railway and water conveyance.

The horizontal section, Fig. 1950, which is reduced from Thorpe's published section, is taken through Barnsley along the dotted line W E upon the plan, Fig. 1949, extending from the millstone grit on the borders of Derbyshire on the west to the eastern boundary of the coal-field at E.

The vertical section, Fig. 1951, represents the position and thickness of the principal beds of coal and mines of ironstone, as they were proved by borings at Wath Wood, near Lundhill Colliery, on the plan, Fig. 1949. Five beds of coal, between the Woodmoor seam and the Kent's Thin seam, do not occur at this place; a second vertical section, Fig. 1952, is therefore placed alongside, showing these beds in their corresponding position as they were proved in sinking at the Oaks Colliery, near Barnsley, Fig. 1949.

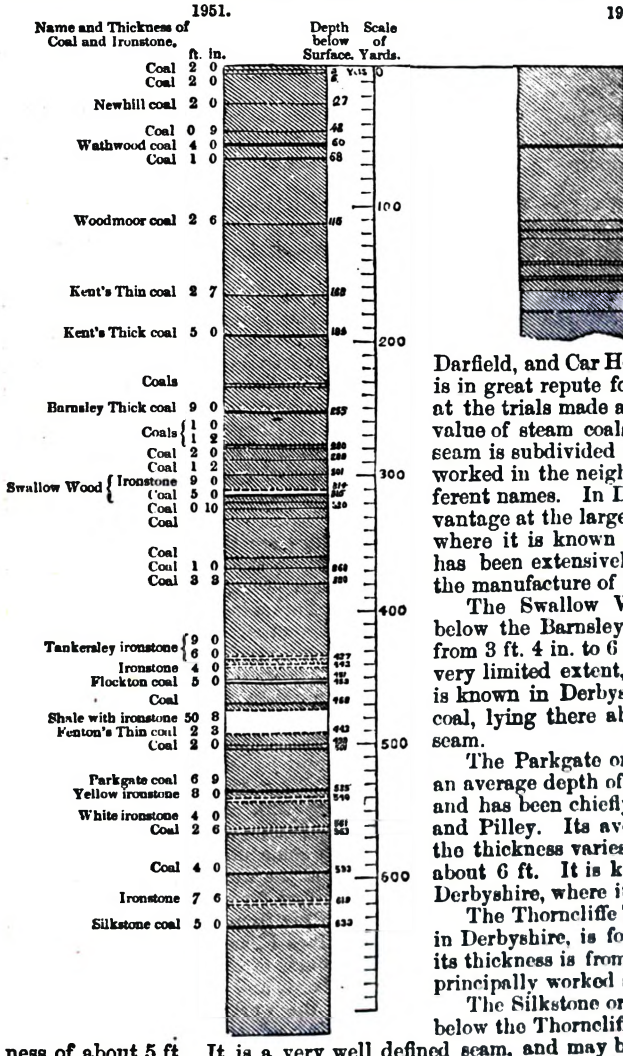
The South Yorkshire coal-field is a continuation northwards of the Derbyshire coal-field. On the east it is bounded by the overlying and unconformable magnesian limestone and Permian strata, and the extent of the coal-measures in this direction is yet unproved. On the west the millstone grit rocks crop out, forming the bleak moors of North Derbyshire; and the coal-measures extend northwards and constitute the North Yorkshire coal-field. The general dip of the coal strata is from west to east at an average angle of 1 in 9; this, however, is much modified in many localities by main faults, the principal of which are shown on the plan, Fig. 1949, by the strong black lines. The total number of coal seams is very great, as shown in the vertical section, Fig. 1951, and many of them have been worked in various localities.

The following are the principal seams of coal in their geological order, with their average thickness:—



| | | | |
|---|---|---|---|
| 1. | Wath Wood or Muck seam | 4 ft. 6 in. | thick. |
| 2. | Coal, no name | 3 8 | " |
| 3. | Woodmoor seam | 3 0 | " |
| 4. | Winter seam | 5 4 | " |
| 5. | Upper Beamshaw seam | 4 8 | " |
| 6. | Lower Beamshaw seam | 2 2 | " |
| 7. | Kent's Thin seam | 2 7 | " |
| 8. | Kent's Thick or High Hazel seam | 5 0 | " |
| 9. | Barnsley Thick seam | 8 ft. 6 in. to 9 0 | " |
| 10. | Swallow Wood seam | 5 0 | " |
| 11. | Howard or Flockton seam | 5 0 | " |
| 12. | Fenton's Thin seam | 2 3 | " |
| 13. | Parkgate or Chapeltown seam | 6 9 | " |
| 14. | Thorncliffe Thin seam | 2 6 | " |
| 15. | Four-foot seam, variable | 4 0 | " |
| 16. | Silkstone or Sheffield seam | 5 0 | " |
| 17. | Charlton Brook or Mortomly seam | 8 0 | " |

The most important seam of the series is the Barnsley Thick coal, which, under the name of the Main, or Top Hard coal, has been very extensively worked in Derbyshire. In the South Yorkshire district its average thickness is about 8 ft. 6 in., but the thickness varies exceedingly at different places. It is most fully developed in the neighbourhood of Barnsley, but extends through the greater part of the district, and has been principally worked at Woolley, Gawber, The Oaks, Edmund's Main, Wombwell Main, Darley Main, Elsecar, Warren Vale, Rawmarsh, Hoyland, Lundhill, Mount Osborne, Thryburgh, Darfield, and Car House. The hard coal from this seam is in great repute for steam purposes, and stood high at the trials made at Woolwich in 1851 relative to the value of steam coals. North of Woolley the Barnsley seam is subdivided into two or three others, which are worked in the neighbourhood of Normanton under different names. In Derbyshire it appears to the best advantage at the large works of Mr. Barrow, at Staveley, where it is known as the Staveley Hard coal, which has been extensively used for steam purposes and in the manufacture of iron.




The Swallow Wood seam occurs about 60 yds. below the Barnsley Thick coal, its thickness varying from 3 ft. 4 in. to 6 ft. It has been worked only to a very limited extent, principally at Swallow Wood, and is known in Derbyshire as the Dunsil or Oldgreaves coal, lying there about 30 yds. below the Top Hard seam.

The Parkgate or Thorncliffe Thick seam occurs at an average depth of 219 yds. below the Swallow Wood, and has been chiefly worked at Parkgate, Thorncliffe, and Pilley. Its average thickness is 5 ft. 6 in., but the thickness varies considerably, from 4 ft. 10 in. to about 6 ft. It is known as the Bottom Soft coal in Derbyshire, where it has been very extensively worked.

The Thorncliffe Thin seam, called the Bottom Hard in Derbyshire, is found 24 yds. below the preceding: its thickness is from 2 ft. 6 in. to 3 ft., and it has been principally worked at Thorncliffe, Pilley, &c.

The Silkstone or Sheffield seam lies about 61 yds. below the Thorncliffe Thin, and has an average thickness of about 5 ft. It is a very well defined seam, and may be taken as a sort of datum line in identifying the position of the other beds. It has been principally worked in the neighbourhood of Sheffield, and at Chapeltown, Thorncliffe, Pilley, Mortomly, and Silkstone, and is identical with the Black Shale or Clod coal of Derbyshire. The coal is of great value for house fire purposes, competing with the celebrated Hetton Walisend.

By far the most important and valuable of the seams of coal are the Barnsley Thick and Silkstone seams. At the Woolwich trials, made by the Admiralty in 1851, relative to the strength

and value for steam purposes of the Barnsley Thick coal from Darley Main, West Hartley coal from Newcastle, and Welsh coal from Merthyr Tydvil, the total weight of water evaporated in each case was 24,960 lbs., and the evaporation a lb. of coal was 8·10 lbs. by the Barnsley Thick and West Hartley coals, and 8·25 lbs. by the Merthyr coal. Trials were also made of the Barnsley Thick coal in 1858 at Doncaster, on the Great Northern Railway, when the evaporation obtained was 7·64 lbs. of water a lb. of coal, the total weight of water evaporated being 448,281 lbs., and the coal used being a mixture of steam coal and house fire coal, consumed under Cornish boilers, working at a pressure of 45 lbs. The Barnsley Thick coal lights easily, burns freely, and raises steam rapidly. It produces only a very small quantity of white ashes and cinders, giving little trouble to the stokers, and the less it is disturbed the better; it does not clog or adhere to the bars, and makes no slag, maintaining a good clear fire with little sulphur. It is a most economical coal for marine engines, and in using it a light thin fire is particularly recommended.

The mines of ironstone occur between the Barnsley Thick coal and the Silkstone coal, as shown in the vertical section, Fig. 1951.

The first mine of importance is the Swallow Wood, about 60 yds. below the Barnsley Thick coal, which has been principally worked at Milton for the supply of the furnaces there. It consists of three measures of ironstone; and an analysis of a sample of the ore by Spiller, of the Geological Museum, gave 26·79 as the percentage of metallic iron.

The Lidgate mine, next below the Swallow Wood, has been extensively worked at Milton, Tankersley, and Thorncliffe.

The Tankersley mine is usually found about 50 yds. below the Lidgate, and is called also the Musselband ironstone, from the number of fossil shells it contains. It has been worked chiefly at Tankersley, and yields about 1500 tons of ironstone an acre.

The Thorncliffe Black mine lies about 70 yds. below the Tankersley; it is worked principally at Parkgate, and used in the furnaces at Milton and Elsecar; and an analysis by Spiller gave 31·16 per cent. of metallic iron.

The Thorncliffe White mine lies immediately below the Parkgate seam of coal, and consists of three measures, containing about 32 per cent. of metallic iron, and yielding about 1500 tons of ore to the acre. It has been worked principally at Parkgate and Thorncliffe, and was formerly worked extensively at the Holmes.

The lowest mine is the Clay Wood or Black mine, consisting of three measures, containing about 32 per cent. of iron and yielding about 1600 tons of ore the acre. It has been got to a great extent at Thorncliffe, and is identical with the Black Shale or Stripe Rake of Derbyshire, which is so much prized by the ironmasters of that county.

The principal iron-works of the South Yorkshire district are at Parkgate, Holmes, Milton, Elsecar, and Thorncliffe, in blast; and at Chapeltown and Worsborough, out of blast.

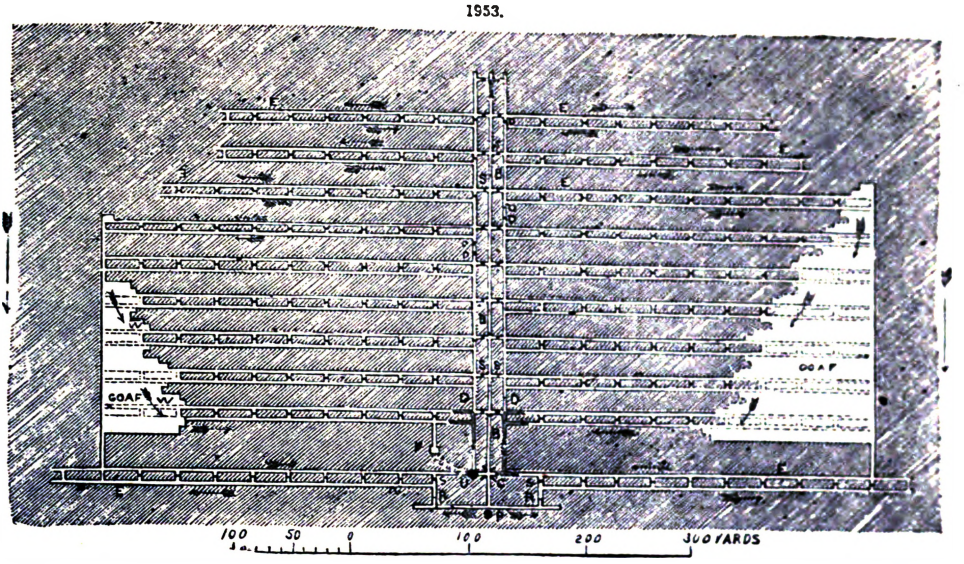
The modes of working the coal in the South Yorkshire district may be considered as modifications of the long-wall system, so extensively and successfully practised in the Midland counties. The pillar-and-stall mode of working adopted in the North of England has not been much used in South Yorkshire; and the long-wall system being principally confined to the Midland counties, the South Yorkshire system of working may be regarded as a combination of the two. Where the circumstances are favourable, the long-wall system is being extended in the Yorkshire coal-field; and wherever it can be adopted, it is to be recommended, on account of the simplicity of arrangement both for working and ventilation, and also as being the most economical method of getting the coal.

The principal modes of working the coal adopted in Yorkshire are the Narrow Work, Long Work, Bords and Long Work, Wide Work, and Bank Work. These are shown in the ideal diagrams, Figs. 1949 to 1968. They can be represented only by ideal plans, because none of them are carried out in their integrity at any collieries in the South Yorkshire district; and in some instances one mode is adopted in one part of the workings, and another elsewhere in the same colliery. These different systems of working, some of which, however, are falling into disuse, have been rendered necessary by the variable nature of the roofs and floors of the coal seams in the South Yorkshire district. The same reference letters are used throughout all the diagrams.

Fig. 1953 is a plan of the mode of working by Narrow Work, on the end of the coal. P is the downcast pit, and B the main bord (road cut transversely to the grain of the coal, against the face of the coal), from which pairs of headings or endings E E (roads cut against the end of the coal, lengthways of the grain) are driven at intervals of about 30 yds. When these endings have been carried to the requisite distance on either side of the main bord B, a communication is made between their extremities, and the coal is worked by short faces homewards, as shown at W W. The whole of the coal being thus got out, the roof is allowed to come down in the goaf as the working progresses, being temporarily kept up immediately behind the working faces by props or puncheons, which are afterwards withdrawn successively and shifted forwards. U is the upcast shaft, and F the ventilating furnace. The main current of fresh air from the downcast pit P is carried up the main bord B and along the farthest pairs of endings E, as shown by the arrows, and is then passed through the face of the workings W. The course of the air is determined by stoppings S built to block up the various crossgates between the bords and endings; and by doors D, through which the coal is brought down to the shaft from the workings W, and from the endings E that are in process of being driven. At C is an air-crossing, where the current of foul air proceeding from the workings to the upcast shaft U crosses over the current of fresh air entering the mine from the downcast pit P. At R R are regulators to control the quantity of air passing through each portion of the mine: when these are closed, the whole of the fresh air has to pass through the workings before reaching the upcast shaft; but when they are opened, a portion of the air finds a shorter course through the regulators direct to the upcast shaft, and a smaller quantity of air therefore passes through the workings. This mode of working is falling into disuse in Yorkshire, and is seldom adopted except under special circumstances, where the coal is of a soft

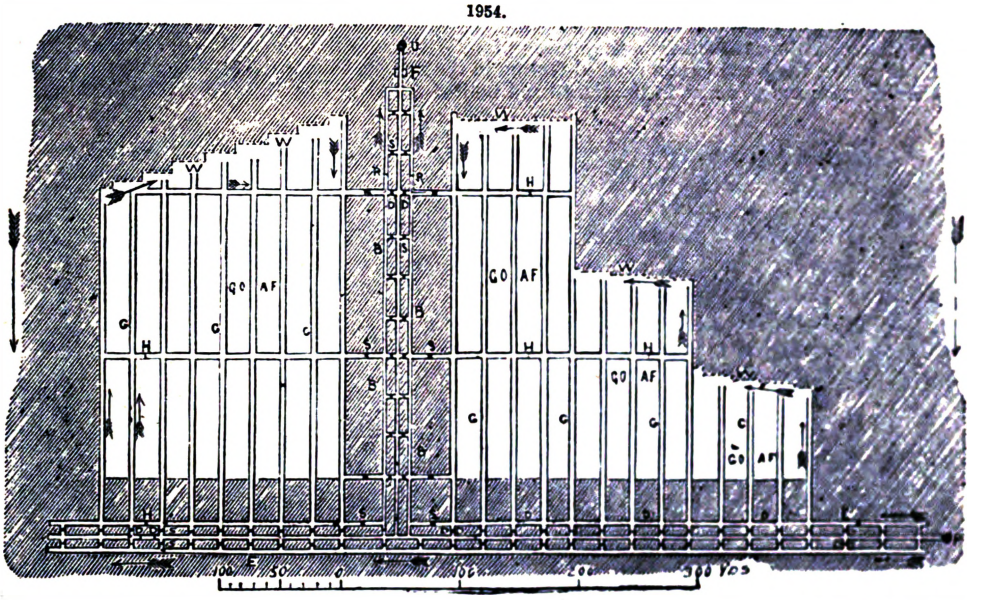
or friable nature and where the roof is not strong, the coal being therefore got in very short lengths, as shown at W W, with only a very narrow face in process of working at a time, whence the name of this mode of working.

1953.




There are two modes of Long Work, the first of which is shown in Fig. 1954. This and all the subsequent modes of working are on the face of the coal, the workings W being carried forwards transversely to the grain of the coal, against the face of the coal, instead of against the end of the coal as in the previous narrow work. In Fig. 1954 it will be seen that there is a long

1954.

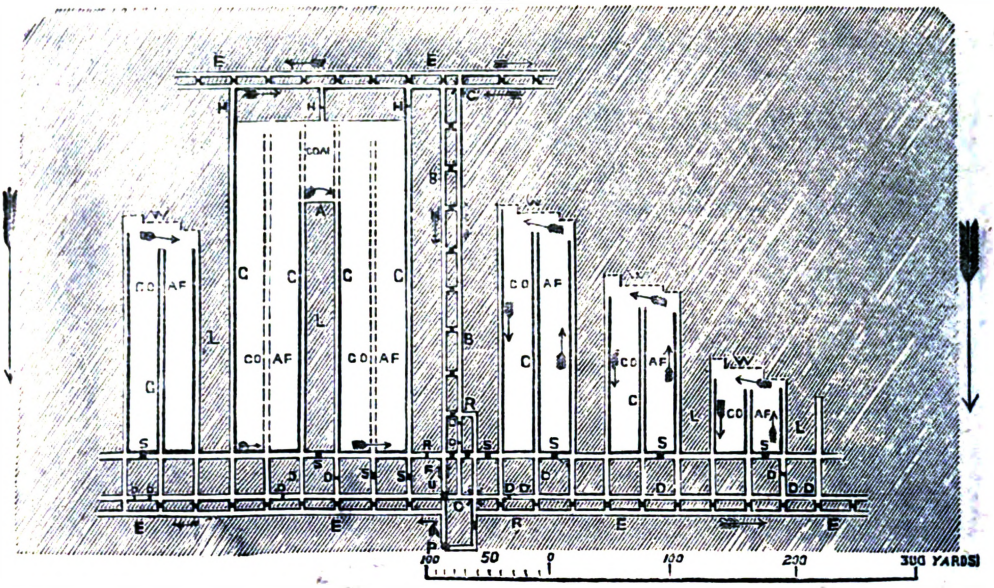



face of work in progress at once in each portion of the mine: the workings are started from the main headings or endings E, and the coal from the working faces is brought down through the goaf by means of packed roads G, shown by the strong black lines, the walls of which are built up of rock and shale; the packed roads are carried forwards continuously as the working faces advance. The fresh air from the downcast shaft passes along the endings E and the packed roads G up to the working faces W, and thence by the bords B to the upcast shaft U, as shown by the arrows, the regulators R R controlling the ventilation in each portion of the workings. At H H are doors or stoppings with apertures to allow of passing some of the air through the packed roads G in the goaf, according as may be required to keep them clear of gas.

In the second mode of Long Work, shown in Fig. 1955, the workings are subdivided into separate lengths of face by the pillars L being left between them at first, about 30 yds. thick; but when the workings have been carried forwards as far as intended, the intervening pillars are then also worked, beginning from the farther end and working backwards, as seen at A, whereby

the current of air is always kept up against the pillar face A until the whole pillar is removed. The packed roads G are required for bringing out the coal through the goaf in this plan of

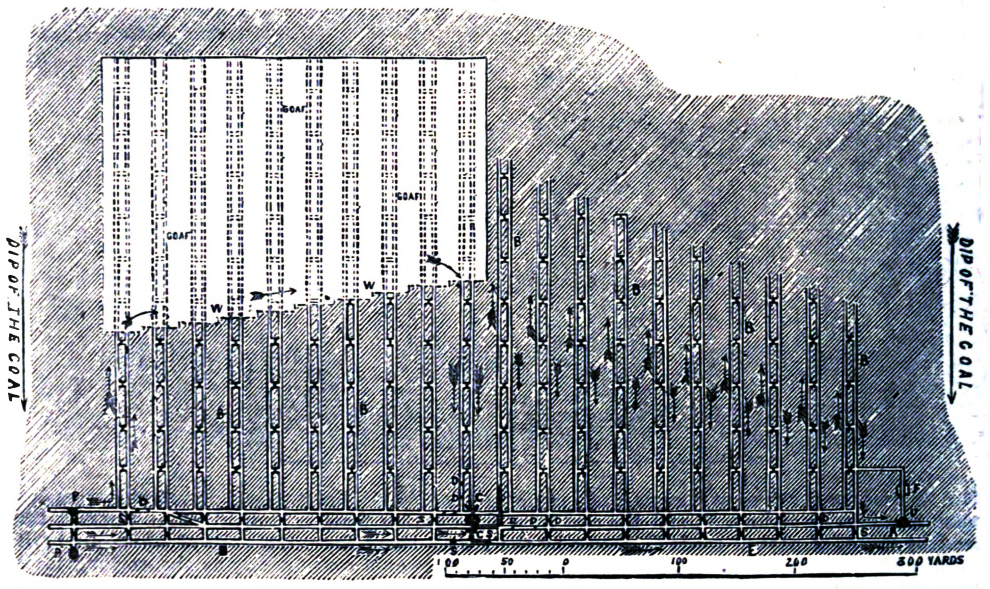
1955.




working, the same as in the first mode of long work; the strong dotted lines through the goaf in the neighbourhood of the pillar working A show packed roads that are no longer required to be maintained, and have been abandoned. The course of the air is shown by the arrows.

The mode of working by Bords and Long Work is shown in Fig. 1956. Here pairs of bords B B are driven from the main heading or ending E, at intervals of about 20 yards; and when they have reached the extreme distance intended, the whole of the intervening coal is worked homewards, downhill, and is brought out from the working face W through the bords B. In bords and long work, therefore, the bords form a marked feature in the system, being driven to the extreme extent in the first instance, as shown in the right-hand half of the plan, Fig. 1956, before the working of

1956.

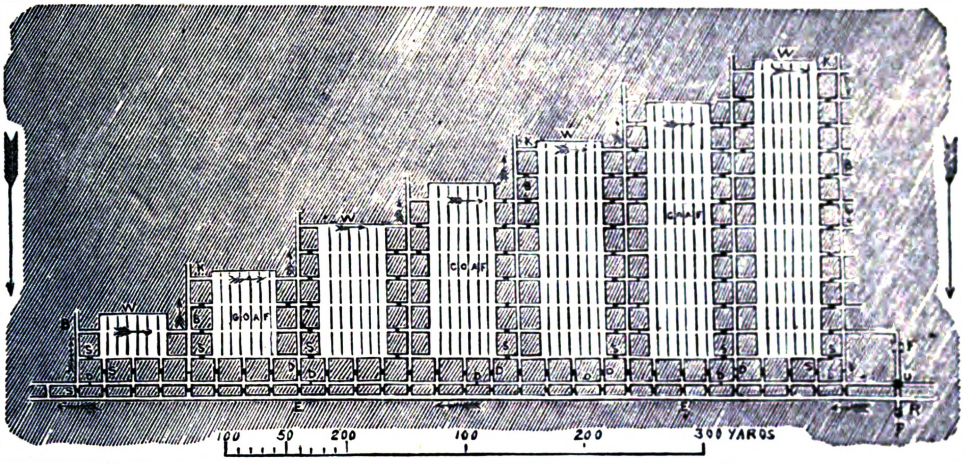



the whole coal is commenced; and when this has been begun, as shown in the left-hand half of the plan, no packed roads are required in the goaf for bringing out the coal from the working face, but the coal is brought down through the bords themselves, which are thus not obliterated till all the coal is won, but remain of service to the last. In the previous modes of long work, on the contrary, shown in Figs. 1954, 1955, the progress of the work is in the opposite direction, uphill, and the face of work is opened without driving bords; and accordingly packed roads are required to be maintained through the goaf for bringing down the coal from the working face. The course of the air is shown by the arrows in Fig. 1956, and the air regulator is placed at R: but in bords and long work

there is no need of any arrangement for coursing part of the air through the goaf, as is required in long work.

In the Wide Work method, shown in Fig. 1957, the coal is got in banks W about 60 yds. long, each subdivided into bords 7 or 8 yds. wide, separated by pillars of an average thickness of 1 yd., as shown by the thick black lines in the goaf. Crossgates K are made to the main roads B at suitable intervals, according to the state of the atmosphere in the mine and the ventilation. For

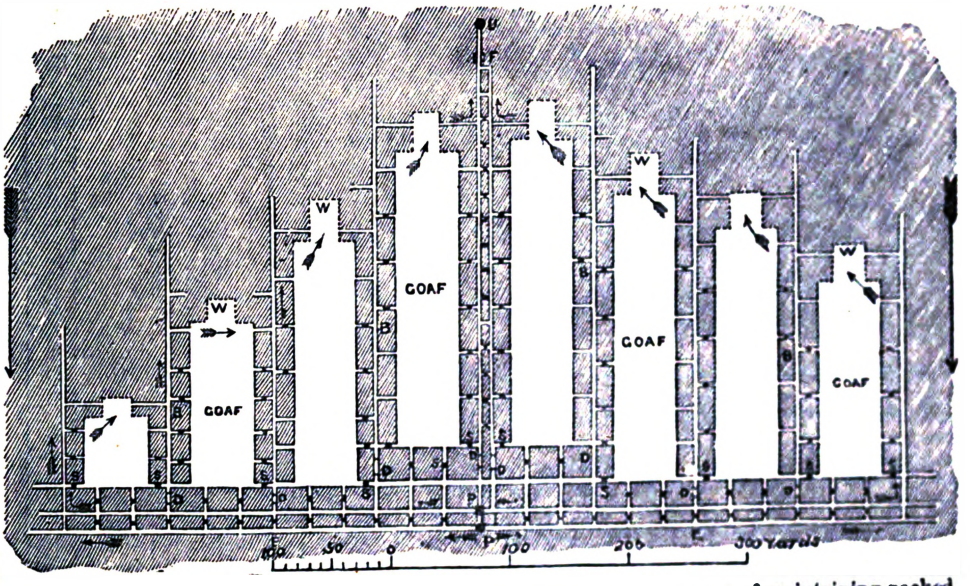
1957.




ventilating the workings the current of air is passed up the farthest bord B, across the face of the work in the first bank W, and out at the other end of the bank; it is then carried forwards up the intervening pillar bord B to the next bank, and across the working face in the same manner, as shown by the arrows. This method of working is now being abandoned where possible for the long-wall system.

In the Bank Work, shown in Fig. 1958, the coal is got in banks W about 60 yds. long, as in the last mode, but each bank is worked all in one length without any intermediate pillars being left in each bank. The method of ventilation is the same as in wide work, as shown by the arrows. The mode of working by single bords B, as in both bank work and wide work, instead of by pairs of

1958.

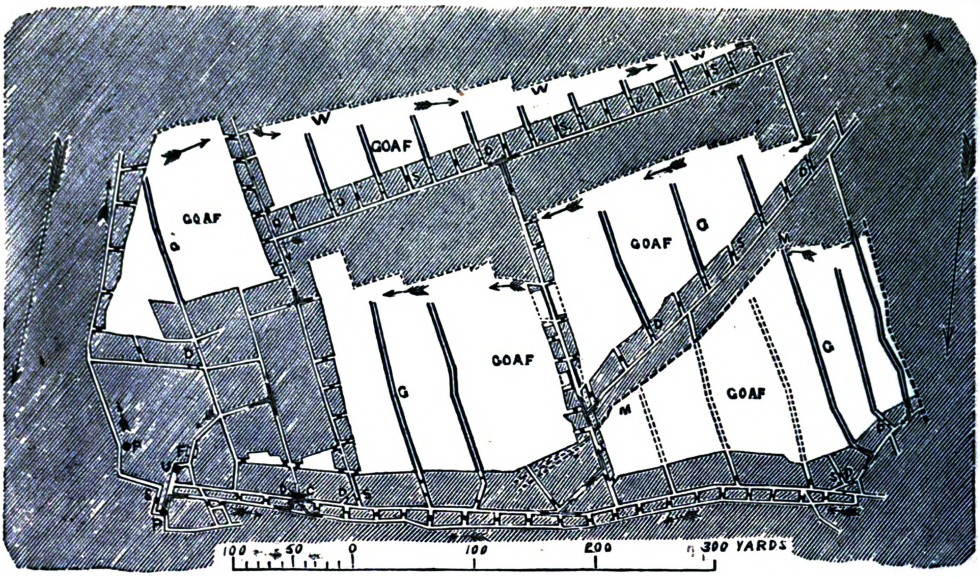



bords, is, however, to be condemned on account of the difficulty and expense of maintaining packed roads through the goaf for the winning of the pillars B B at the last; or if they have not been maintained, of making new packed roads for ventilation: and again, these pillars being liable to a heavy pressure, the coal in the pillar working is rendered of little value.

The plan of the Long Wall system of working, Fig. 1959, shows the difference of this system from any of the ordinary Yorkshire methods of working described above. This is not an ideal plan, but a plan of the actual long-wall workings of the Parkgate seam at the Wharncliffe Silkstone Colliery near Barnsley, Fig. 1949. There is here no loss in getting out pillars, as all the coal is

excavated at one operation. The ventilation of the mine is at the same time considerably simplified, the current of air having altogether a shorter and less tortuous course to follow from the downcast shafts P to the upcast U, as shown by the arrows. The thick dotted line M M shows the position of a fault in one portion of the mine, and the workings are therefore laid out at that part conform-

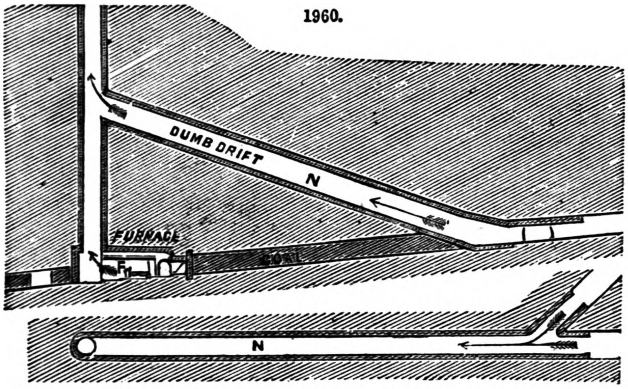
1959.



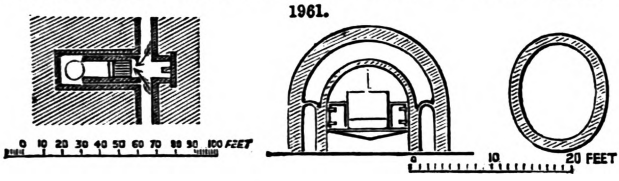

ably with the course of the fault. By the long-wall system a working face of 430 yds. is here obtained in a single length without interruption, as shown at W; and in the lower portion of the workings along the fault M M another face has been opened of the same total length, but divided into two shorter faces by a pillar bord, for safety and convenience of working in the neighbourhood of the fault, the intervening pillar being removed before that portion of the mine is abandoned.

Various supports for the roof are used in the Yorkshire seams: wooden props or puncheons are adopted in some cases; in others, piles of wooden blocks called chocks or clogs; and in others, packs of rock and shale. Cast-iron puncheons also are now being extensively introduced, one of which is shown in Figs. 1965, 1966.

1960.




1961.

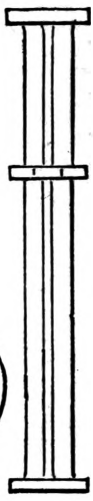



1962. 1963. 1964.

1965.

1966.

1967.



1968.

Two of the greatest difficulties that have to be contended with in mining are Water and Gas. With regard to Water, the mines in the South Yorkshire district are not in general heavily watered in comparison with other mining districts; the workings nearer the outcrops or bassets of the seams are generally more watered than the rest. Except in some special instances there are few collieries where large pumping engines are required: lift pumps are used exclusively, and even tubbing has

scarcely ever been resorted to. A remarkable inundation occurred in 1861 at the Woolley Colliery at Darton, near Barnsley, Fig. 1949, which is working the Barnsley Thick coal: the coal is drawn up a long inclined plane extending from the outcrop of the Barnsley Thick seam and following the dip of the seam; and the water is raised by means of flat pumps. On the 13th April, 1861, a sudden irruption of water into the workings took place, to such an extent that they were almost entirely filled. The water entered through a fissure in the overlying rock, which is of considerable thickness and is full of cracks and fissures towards its outcrop. It is probable that a large amount of head or drainage water had accumulated in these fissures while they remained closed, and that they afterwards became opened by subsidence of the strata in consequence of the working of the coal: the water was found to be drawn away from a well in the rock at the surface, 170 yds. above the coal. The accumulation of water must have been very great, as it continued rising in the day drift a fortnight after the inundation had occurred, at the rate of more than 1 ft. an hour, although a double 10-in. pump had been kept continuously at work; but its rise was subsequently stopped by additional pumping power.

In the amount of Gas generated by the different seams of coal there are great variations. The most terrible explosions have taken place in the Barnsley Thick coal, especially at the Darley Main Colliery, the Oaks, Warren Vale, and Lundhill; the Barnsley Thick and Silkstone seams being specially liable to sudden and powerful emissions of gas. The ventilation is produced by a furnace, shown in Figs. 1960 to 1963, situated at F in the diagrams, Figs. 1954 to 1958, at the bottom of the upcast shaft U, by which a fresh current of air is kept continuously flowing through the mine, so that any gas issuing from the coal is speedily diluted and rendered harmless. For distributing the air through the workings, the stoppings S, doors D, and regulators R are arranged in proper places. The division of the air into separate splits, each of which ventilates a distinct portion of the workings by means of the crossings or overcasts C, and the "scale doors" or regulators R, may be considered, if properly carried out, one of the best preventives of explosions in these very fiery South Yorkshire mines. All the return air should be conducted into the upcast shaft by a dumb drift N, Figs. 1960 to 1963, so as not to pass through the fire of the furnace; and the underground furnaces, whether closed or otherwise, should be fed with nothing but fresh air direct from the downcast shaft.

At some of the mines in the district, belonging to Fitzwilliam, large fans driven by steam power have been substituted for the furnace generally used elsewhere; they are a simple and efficient means of mechanical ventilation, well worth the consideration of all interested in mining, and have now been continuously working with complete success for several years. In the early periods of mining the only ventilation was the natural ventilation, the current of air through the workings being produced simply by the colder and denser air from the downcast shaft displacing the hotter and rarer atmosphere of the mine. Sometimes rarefaction was increased by putting a pan of coals in the upcast shaft; but the consequence of such imperfect ventilation was that the workings were sometimes stopped for many days together. Natural ventilation could, of course, be adopted only when the shafts were of moderate depth and the workings on a limited scale.

In the South Yorkshire district, safety-lamps were first used exclusively at the Oaks Colliery, in the workings of the Barnsley Thick coal, where Stephenson lamps are used in preference to Davy's; and the use of safety-lamps has since extended to many other collieries. At the Wharncliffe Silkstone Colliery, near Barnsley, working the Silkstone seam, Stephenson and Davy lamps are used exclusively; and as the coal-field is very much cut up with faults, the gas cannot be bled away, but as each fault is cut through the greatest caution is required in dealing with the gas in the solid coal beyond, *in bye*. In addition to the use of safety-lamps, an abundance of air should be taken into the working places of fiery mines. Since the explosion at Lundhill in 1857, safety-lamps have been exclusively adopted there. The importance of their use in fiery workings was strongly shown at the Oaks Colliery in 1857, when an outburst of gas took place in the workings down the engine plane, so violent that it was compared to the roar of a draught in the furnace. All the Stephenson lamps were put out, and the Davy lamps were ignited internally, the gauze becoming red hot. As the outburst of gas occurred within a hundred yards of the main intake to the upcast shaft, and a large quantity of air was passing this part at the time, the gas was soon diluted and carried away; and in less than an hour the only traces that remained were found at one or two places where the floor had been upheaved. Thus no doubt a terrible explosion had been averted by the use of safety-lamps; but if any one of the lamps had been out of order, or the gauze smeared with oil or coal dust, or if any naked light had been in this part of the workings, an explosion would inevitably have occurred.

COAL-WASHING MACHINE. Fr., *Machine à laver les houilles*; Ger., *Kohlenwaschmaschine*; Ital., *Macchina da lavar litantrace*; Span., *Máquina para limpiar carbon de piedra*.

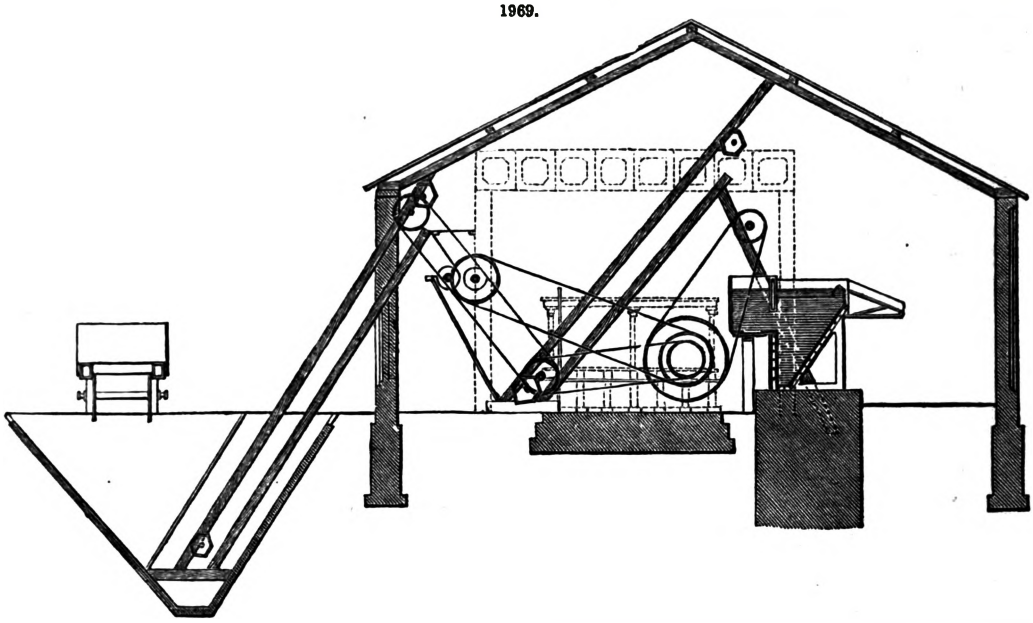
We give, Figs. 1969 to 1973, a set of coal-washing apparatus and coke ovens at one of the establishments of the Wigan Coal and Iron Company. The washing machinery, which is contained in a building 48 ft. long by 24 ft. wide, consists of four iron chambers, each of which is in free communication with a cylinder placed at one end of it, as shown in the plan, Figs. 1970 to 1972. These cylinders are each 3 ft. in diameter, and the pistons working in them have a stroke of 3½ in., and are driven at 150 strokes a minute, so as to keep the water within the chambers in a state of constant agitation.

The coal to be washed is discharged from the railway wagons into a large hopper outside the building, and it is lifted from this hopper, Figs. 1969, 1970, by the elevator shown in the section, Fig. 1970, this elevator delivering it to the crushing rollers, by which it is reduced to a uniform size. After passing the crushing rollers, it is taken up by a second set of elevators, and delivered to the washing chambers, or bashes, down a trough laid at an easy gradient, this trough having four compartments, down which the coal is washed by a small stream of water. The coal, during the process of washing, is placed on perforated copper screens or sieves slightly submerged in the water contained in the bashes, and the pulsation of the water, occasioned by the action of the pistons, causes the good coal, which is the lightest, to be washed over into the shoots with which

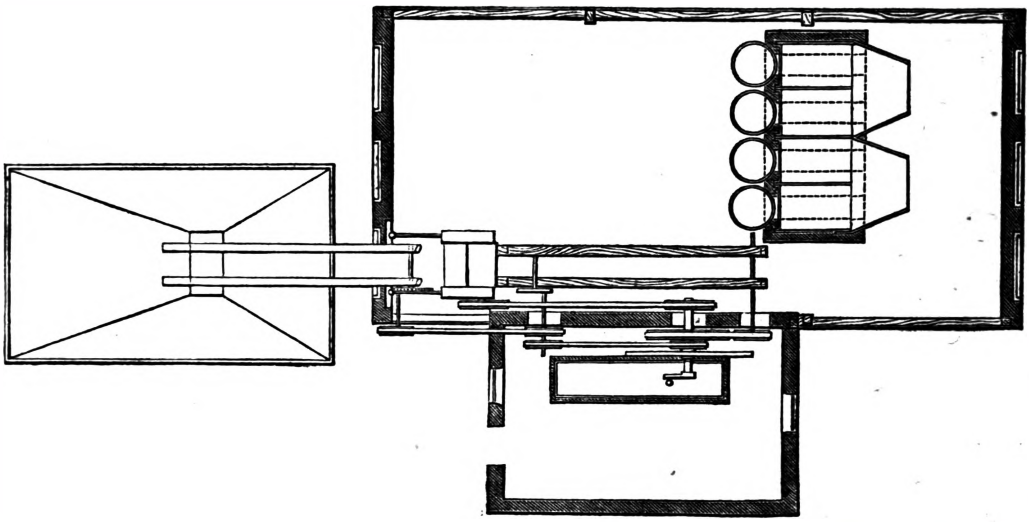
the chambers are provided. The pyrites, on the other hand, being heavier, fall down and lie on the perforated sieves; and at regular intervals the sluices are opened, and the pyrites allowed to fall into the chamber below. At the bottom of each chamber there is another sluice, which is opened occasionally to allow the refuse to be discharged into wagons placed to receive it. The good coal from the shoots of the bashes is also delivered directly into wagons.

The washing machinery, elevations, and so on, are driven by a beam engine, with 14-in. cylinder and 2 ft. 6 in. stroke, arranged as shown in Figs. 1969, 1970. The loss by washing is about 10 per

1969.



1970.



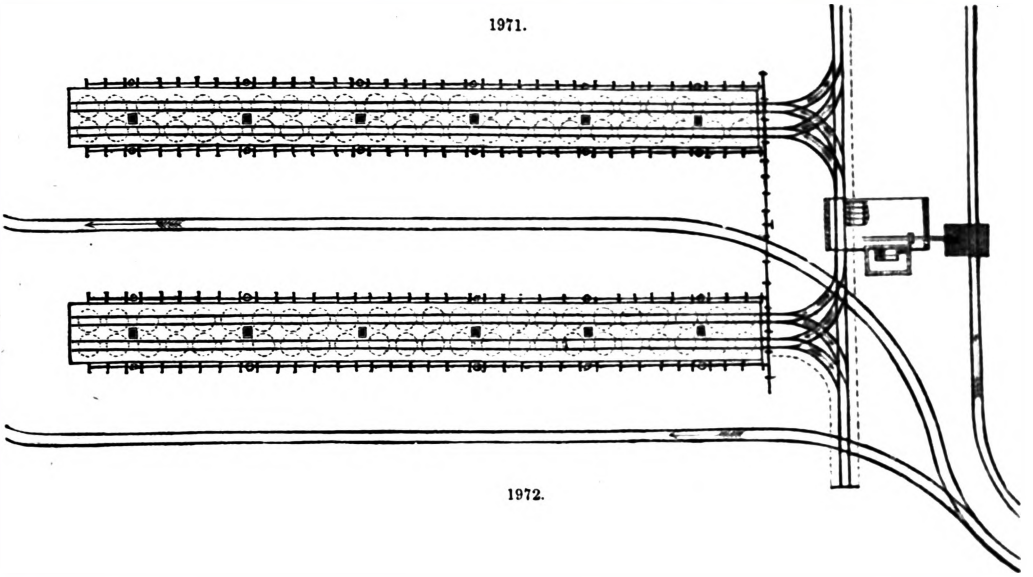
cent., by weight, of the gross quantity of coal passed through the machine. Several machines of the kind we have described are in use at the Wigan Coal and Iron Company's works; and they turn out from 300 to 350 tons of small coal a day.

The general arrangement of the coal-washing machinery and coke ovens will be understood from the general plan and section, Figs. 1971 to 1973. From this it may be observed that the ovens, which are each 11 ft. in diameter and 8 ft. 6 in. high, are arranged in two parallel double rows, a chimney being provided for every eight ovens. The charging is performed by the aid of a tramway laid over the tops of the ovens, Fig. 1973, the coal dust being brought from the washing apparatus in 25-cwt. hopper wagons along this tramway, and dropped through holes left in the crown of the ovens for this purpose. The charge of each oven is 8 tons, and this charge is allowed to burn five days or 120 hours. This, when burnt, is cooled by the aid of a water-pipe inserted in the oven, and is afterwards drawn out by rakes.

One of the most successful of recent coal-washing machines is that constructed by M. Evrard for

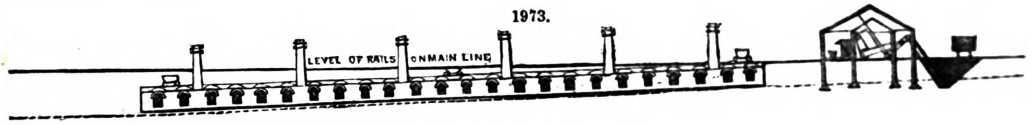
the mines of La Chazotte, in France, Figs. 1974 to 1976. Figs. 1974 and 1976 are vertical sections through the machine in two directions at right angles to each other, and Fig. 1975 is a plan of the whole. The special object in view in this construction is the washing of very large quantities of coal of comparatively unequal size, and the separation of these different sizes by the aid of the washing process. This large washing machine is thereby enabled to combine the advantages of machine labour with the superior quality of work performed by hand-washing. The coals are

1971.

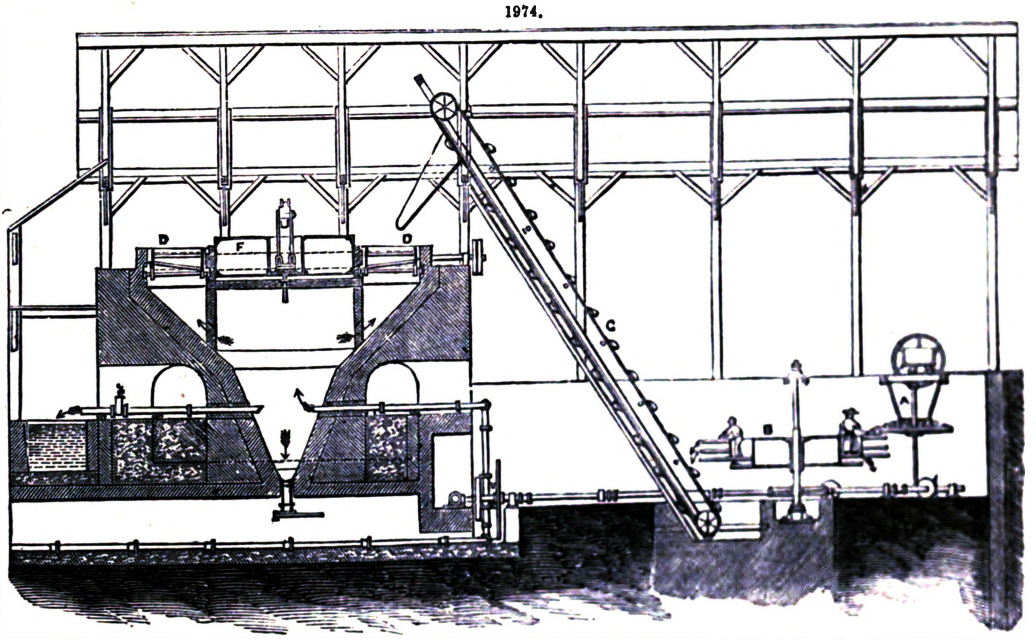


1972.

1973.



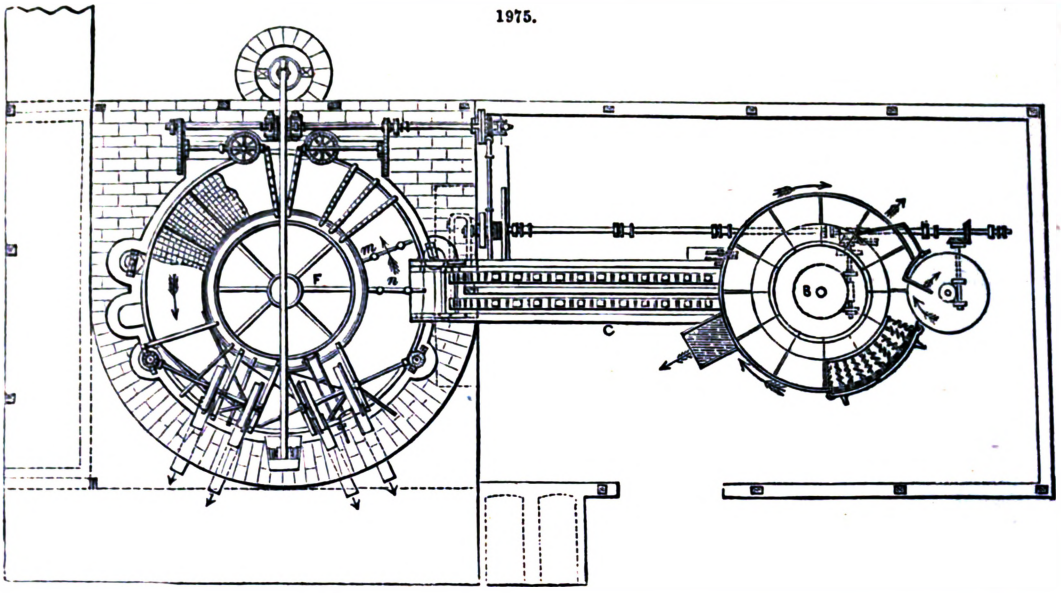

1974.




thrown into a hopper A, Fig. 1974, with a revolving base upon a larger revolving screen, where the largest pieces are freed from stones by hand, two workmen being placed upon the screen B, and carried round by the latter in its revolution. There are two screens with narrow openings below this first, and they deliver the smaller coal by means of two elevators C, to the top of the washing machine. Each kind of coal is brought up separately, and thrown upon a circular table D, which revolves slowly round a large fixed cylinder E, containing the floating piston F. The two elevators

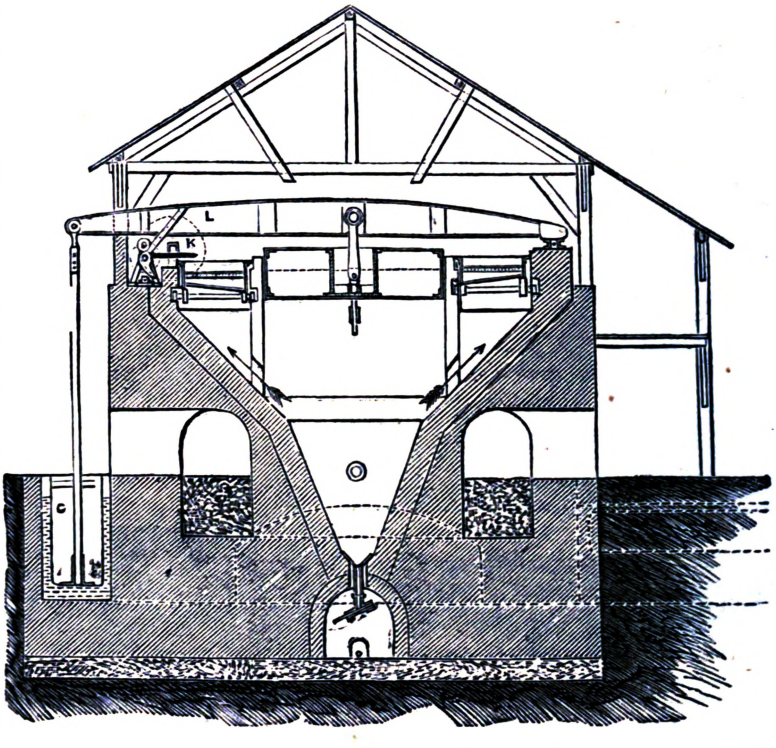
bring the coal up to the circular table, and it is levelled there by two scrapers fixed in different heights (*m n* in plan, Fig. 1975), so that a stratum of small coal is spread over a layer of larger coal below. The central part of the machine is filled with water, and the floating piston F is moved up and down in the water by means of a lever L, Fig. 1975, worked by a cam. The lever

1975.




is counterbalanced by a float G, immersed in water, and its movement causes an alternating up and down current of water through the screens in the revolving table D, by which the different materials mixed together in the unwashed coal slack separate themselves in parallel horizontal layers, according to their difference of specific gravity, and also according to their size of grain. There is, however, one thing of great importance required for a successful operation, namely, the agitation of the water must commence with great power, and must successively diminish in force as the washing proceeds, since the first action effects the settlement of the very largest pieces of stone at the bottom, and of the large-sized coal in a stratum immediately above that. This being done, it requires a more gentle agitation, so as to leave the lowest layers undisturbed, while operating through these upon the superposed strata of small-grained materials, so as to give the small pieces of stone and other heavy matters an opportunity to pass through the coarse-grained coal down to the lowest stratum of stones. With a uniform action of the machine, M. Evrard obtains this important result, by inclining the table against the water lever, as shown in Fig. 1976. He thereby obtains a greater immersion of the table, and, consequently, a more powerful rush of water through its sieves at the one part of each revolution, and a less powerful action at the opposite side where the coal is partly raised above the water-level.

1976.

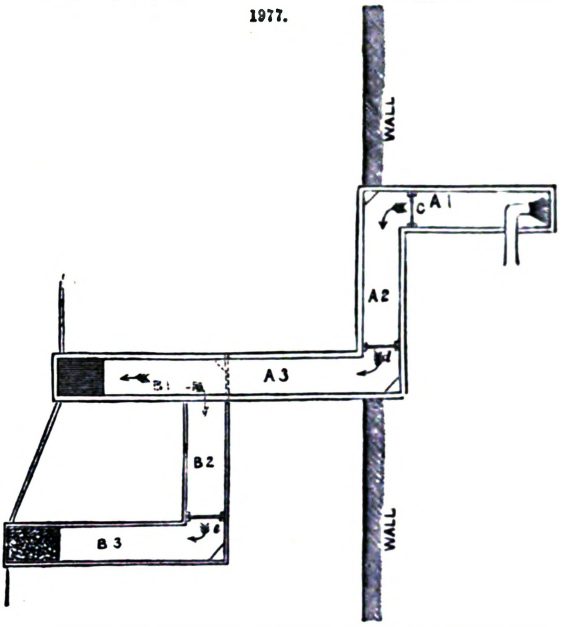



The body of this machine is constructed in masonry, in the shape of an inverted cone, with a diameter of 33 ft. 6 in., and a height of 32 ft. 10 in. Its bottom opens into a drain-pipe for removing the mud collected there. The floating piston is 17 ft. 4½ in. in diameter. The table D is 32 ft.

10 in. in diameter, and 6 ft. 6¾ in. wide. It is perforated with holes of $\frac{1}{12}$ in. in diameter. The inclination of this table amounts to one foot for the whole length of the diameter of the table, the depth of layer of coal is 6 in., and the water-level 8 in. over the lowest point of the revolving table. The coal is removed from the table after having passed through one entire revolution by means of four scrapers placed at different heights, so as to remove each another of the superposed strata of coal ranged according to the size, the smallest coal being raked off from the top, while the lower layers give coarser-sized coal in proportion to the depth. The lowest stratum is formed by the stones and other heavy impurities of the coal, and this is removed whenever it has reached a certain height. The washing process, as carried on with this machine at Chazotte, reduces the contents of ashes of the coal slack from 15 to 17 per cent. on the unwashed slack down to 8 or 9 per cent. The production of one of these machines is 138 bushels for each revolution, and, taking the speed at the average adopted at Chazotte, namely, one revolution in five minutes, with 100 strokes of the piston during that time, the total production is 1650 bushels an hour. The total power required for the complete machine, with its revolving screen and elevator, is 10 horse-power.

A very simple mode of washing the impurities out of small coal has been at work at South Tyne Colliery, Haltwhistle. The machinery employed consists of an arrangement of boxes or troughs, into the upper series of which, A 1, A 2, A 3, Fig. 1977, the water for washing is conducted by a pipe P. At the end of A 3 is a small screen, formed of ⅜-in. round iron rods, placed about ⅛ of an inch apart; immediately below this screen another series of troughs, B 1, B 2, B 3, is similarly arranged, terminating with a perforated zinc plate placed in a sloping position like the screen in the upper series. The upper troughs are 2 ft. 4 in. wide and 13 in. deep; the lower ones are 2 ft. 5 in. wide and 6 in. deep.

1977.




At *c*, *d*, and *e*, Fig. 1977, grooves are placed, into which slips of wood are inserted, one above another, at different stages of the washing; these partially check the current of water, and assist in collecting the stones, pyrites, and so on. W, Fig. 1978, is the wagon-way, by which the coal is brought to the washer.

It will be observed that the pipe P is bent so that the water pours *against* the end of the trough; this has been found to act better than when the water is poured in the contrary direction. The mode of working is apparent; an operator shovels the coal into the trough, and another with a rake spreads it and keeps it under the action of the current. The water that passes through the screen carries much of the smaller coal with it; to obviate this the lower series of troughs were erected, along which the water is conducted, and finally passed over the perforated zinc plate. The velocity of the current is regulated, when required, by raising or lowering the troughs, their arrangement being such that this is easily effected. With this apparatus two operators can wash three wagons of coal an hour.

1978.

See ARTESIAN WELL. BORING AND BLASTING. CAGE. FUEL. HAULAGE. IRON. LAMPS, *Safety*. VENTILATION.

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COAST DEFENCE. FR., *Fortification Maritime*; GER., *Küstenbefestigung*; ITAL., *Difesa delle coste*; SPAN., *Defensa de la costa*.

*Coast Defences.*—The defences of coasts and harbours, especially those of an island like England, where if attacked the assault must be delivered more or less immediately from the sea, forms an important branch of the general technical art of fortification; with this considerable difference, however, that while the works of an inland fortress or strong place are generally constructed with a strict regard to certain rules laid down for the different systems of celebrated engineers, the acknowledged heads of their profession, the defences of a coast must in a great degree depend on local circumstances, and, if secure from an attack on the land side, do not require to be furnished with the appliances for a protracted siege. The struggle with an enemy afloat and unsupported with land forces would then be short, sharp, and decisive, the victory remaining to the hardest

hitter, the biggest gun, or, perhaps, to the craftiest-laid torpedo. In like manner, the proper placing and construction of coast defences emancipates, as it were, the officer of engineers from the more mechanical operations of permanent fortification, and, if he possesses genius, enables him to take advantage of every natural feature, both above and below the water-level, either for defence or offence, and make the most of them.

*Their History.*—Although in the very dawn of Jewish, Greek, and Roman history we read of the walls and other fortifications of towns, we do not find any mention made of impediments to prevent invaders landing on their coasts, except occasionally a free fight on the beach, such as the Greeks appear to have experienced when they reached the shores of Troy. When Julius Cæsar landed on the Kentish strand, he had, it is true, to break through a bulwark of half-naked blue-stained Britons, which his heavy-armed legionaries soon proved too strong for. William of Normandy met with considerable opposition when he disembarked as an invader; but he eventually conquered. In most cases we find the invaders securing themselves a safe haven or tête-de-pont for return in case the fortune of war should declare against them. Thus the Greeks fortified their ships on the shores of Troy, and the Romans created the germs of the future fortifications and defences of Dover and Portsmouth, and perhaps the Thames. But in the first few centuries after the Conquest the constant wars between England and France exposed both nations to the visits of hostile fleets, and subjected the unfortunate inhabitants of our sea-board to much misery, especially on the south and east coasts. We can yet see in the Isle of Wight the existing outline of a town (Newtown) burned by the French fleet in the time of the second Edward, and which remains, with its houseless streets and market-places, a desolation to the present day. Even localities so remote as the Welsh coasts were not safe, as we read that in 1405 the French landed at Milford Haven and plundered Carmarthen and other towns, safely regaining their ships; while as late as 1758 we retaliated by sacking the now impregnable Cherbourg, and levying a tribute on its Monts du Piété and other public institutions.

As the invention of artillery, however, grew in importance, the attention of our rulers seemed turned to the necessity, on certain points of our coasts at least, of securing the cities and towns situated near them from being burnt or plundered with impunity; and the sequestrations of the rich monasteries in Hampshire and the Isle of Wight furnished the eighth Henry with funds sufficient to erect the castles of Southsea, Hurst, Sandown, Yarmouth, and Calshot, as well as to fortify the narrow entrances into the harbour of Portsmouth, which was then, as now, considered the first naval arsenal of England. Besides these, we owe to Henry VIII. the defences of Falmouth, Plymouth, Pembroke, Deal, and other important points on the coast. In Queen Elizabeth's time the defences of Milford Haven, the Thames, and Plymouth, as well as minor works on the Kentish and eastern shores, were not neglected by her shrewd and far-seeing ministers, and the many existing traces of the reign of the Stuarts in the old fortifications of Portsmouth, Devonport, Sheerness, Gravesend, and other places along the coasts, although erected more probably from dread of a Dutch than a French invasion, show that neither Charles nor James neglected the defence of England on its then weakest and most accessible points. During the reign of Anne and the first two Georges the constant dread of descents from the partisans of the Pretender, or his French and Spanish allies, caused further extensions of our coast defences; and when the French fleet rode triumphant in the Mediterranean, after the fall of Minorca and execution of Byng, we deemed it necessary to strengthen the land defences of Portsmouth by the first fortifying of the old Hilsea lines. It is a curious thing that one of our ancient northern coast defences, namely, the Old Fort on the Bass Rock, was the last spot in Great Britain that held out for the Stuarts. The long wars of the French Revolution, although our fleets finally swept the seas of our enemies, still demanded constant attention to various exposed and unprotected points of our coast; but it was not till France again had a navy, and the defences of Cherbourg, Cronstadt, and Sebastopol created, as it were, a new era, and the due progress of things produced the Crimean and American wars, that the subject was really taken up in a comprehensive and extended manner; our eyes seemed suddenly opened to the utter worthlessness of many of our existing works, and an honest effort made to effect all the improved modes of fortification now absolutely necessary by the monstrous strides that modern science has made in the weapons both of offence and defence. The Report of the Commissioners appointed to consider the defences of the United Kingdom, dated the 7th February, 1860, entered fully into the details of their existing state, and gave their recommendations for their augmentation or renewal; and until the present time immense works, costing an aggregate sum of at least nine millions both in coast and inland defences to our harbours and arsenals, have been carried on, subject however to the disadvantage of the ever-changing increase in the weapons of attack and a corresponding increase ever forced on them in those of defence, causing works which might have been deemed perfect a few years ago to be now nearly useless or obsolete.

*Reconnaissance of a Sea Frontier.*—In addition to the general descriptions necessary in making a reconnaissance, that of a sea-board line should clearly describe the nature of the coast; whether it is bordered by dunes or sand hills, or edged with flat rocks in shallow water which would render access to it more or less dangerous, or by cliffs which would render it altogether inaccessible; the points on which descents could be easily made, the rentrant angles affording sheltered creeks and anchorages; the high lands and capes affording eligible sites for the erection of forts and batteries should be clearly pointed out, with the height of each above the ordinary high-water level, also all islets and rocks capable of being made available for advanced works, such as towers, and so on; the shoals, creeks, roads, and ports, with their soundings, the nature of the winds necessary for entering and sailing out of these ports, of which it will be requisite to note the local peculiarities; the state, garrison, and armament of the different batteries established for the defence of the anchoring grounds; the field-works, if any, formed on points where descents might be practicable; the camps, fortified towns, and other strong places which cover or protect the principal maritime establishments or military arsenals; finally, to analyse

carefully the existing system of defence, and to consider the best mode of forcing it. If rivers have their mouths on these coasts it is necessary to consider very carefully the influence of the tides on their entrances. It is not less essential to indicate the hours of high water at all the principal points and ports, and the period of tide more or less favourable to the approach to the different points of disembarkation. To these general remarks, taken from the French 'Aide Mémoire,' we may add that in modern warfare it will be very necessary to take into consideration the various lines of railway by which forces from the interior may be suddenly concentrated so as to crush any inferior or isolated body of men who may seek a hostile landing on a coast, and also the facilities which may exist for the placing of obstructions either floating or hidden.

*General Principles of Coast Defence.*—Before entering into this subject it must be premised that, while we write, some of the most important points of coast defence are involved in much doubt, and must be considered as subject to important changes, according as the experiments on our guns, our ammunition, our armour, and our obstructions, floating or otherwise, present from day to day new phases. We can therefore only offer a few useful general principles on the subject from the best modern authorities, simply reminding our readers that the great question of ships *versus* forts and iron *versus* earth yet remains to be solved, when the giants of the earth again do battle.

Von Wurmbs, in his 'Lehrbuch der Kriegs Baukunst,' remarks that the defence of a sea-surrounded country, or an extended line of coast, requires in the first instance movable bodies of troops cantoned near the most important points, and acting in co-operation with divisions of the fleet, flotillas of gunboats, and war steamers. Well-arranged lines of railway and telegraph will be here of great importance. Fortresses are, however, necessary at the principal arsenals, dock-yards, and other sources of supply, as well as at those points where the landing of a large body of an enemy's troops might take place, and so enable them to attack us on the land side.

The fortification of the principal important points of a coast line, such as our war havens of Portsmouth, Sheerness, Plymouth, Milford Haven, and Cork Harbour, also demand an enceinte on the land side capable of withstanding a sudden assault, and outworks which are strong enough to defy a regular attack, to resist the operations of a hostile fleet, and finally to keep the enemy at such a distance as to prevent a bombardment of the place and its establishments. This has been the principle adopted in the modern land defences of our naval arsenals, which are now surrounded with substantial forts as well towards the land as the sea, so as to hold an enemy at bay until our forces could be hurried up from all sides. On other points, coast batteries or forts of a minor magnitude become necessary to defend roads, havens, or anchorages, to protect the interests of commerce, or to hinder the landing of an enemy; due precautions should in all cases be taken to secure the rear of these batteries from surprise by proper gorge walls, and so on.

As, nevertheless, fortresses cannot defend every point, or be placed close enough to hinder the passage of a powerful fleet, we must therefore in such cases take advantage of floating and hidden obstacles of every kind, such as torpedoes, floating batteries, booms, chains, rope nets, and so on.

Coast fortifications, it must always be considered, are opposed against the power of a most formidable enemy. In the present day we must consider the enormous and still increasing armaments, both in number and weight, of modern ships, and their armour creeping up from 4 in. to 15 in. in thickness. Even frigates which a few years ago were seldom equipped with anything heavier than an 18-pounder, now carry 12-ton guns, discharging a 300-lb. bolt. Also, in a proper depth of water, ships can change their position easily and quickly, and by the help of steam can tack in the face of contrary winds and lay their broadsides full on against the opposing forts, unless these are situated high enough above the water-level.

But, on the other hand, many circumstances favour the defence of fortresses against ships when unsupported by land forces. The most formidable position of ships in attacking a coast defence is no doubt with broadside on, and, theoretically at least, as close as possible; but in taking up this position, if the ship, not of course a turret, allow itself to be raked by the fire of the fort, it is in the first place quite powerless to return a gun, and its sudden destruction may in many cases take place. If the wind suddenly changes, the keel touches a shoal, or a shot knocks the machinery out of gear so as to hinder its withdrawal from an enemy's fire, then it may be destroyed by the guns of the fortress, if they are heavy enough to penetrate her iron plating; for in modern warfare we must consider all fighting ships as thus protected. This fate very nearly met our fine 90-gun line-of-battle ship the 'Albion' and 50-gun frigate 'Arethusa,' by the fire of two or three guns only of the little Wasp and Telegraph batteries, on the heights of Sebastopol Harbour, on the 17th October, 1854. In modern times, many brilliant examples of this have been given. One large shot striking a line-of-battle ship near the water-line may sink her, or a shell bursting through her decks explode her magazines.

Fig. 1979 shows the defences of the entrance to Sebastopol Harbour, and position of the cliff batteries and attacking ships. The figures show the height in feet above high-water mark.

We may here remark the circumstance that coast batteries have generally a very large object to aim at,—a line-of-battle ship, for instance, from 200 to 300 ft. in length, and, with her sails and rigging, 60 to 80 ft. in height; while the ship may have no target to fire at but an open coast battery, covered with a strong earthen shield, and with the muzzles of its guns not rising more than 1½ ft. above the crest.

It is desirable to have the guns of a small battery as much as possible of the same calibre, if not of the same nature. It must be also considered that a ship changing its position at the rate of 8 knots an hour moves 600 yds. in 2½ minutes; therefore to meet this, not a single gun, but a number on each battery, will be found necessary and most efficient to injure a passing fleet.

Previous to 1861 not less than twenty-three varieties of guns were mounted on our coast batteries, after which period the number was restricted to five varieties, namely, the 10-in. gun of 86 cwt., 68-pounder of 95 cwt., 8-in. of 65 cwt., 32-pounder of 56 cwt., and 13-in. mortars; but with

the late imagined improvements in artillery our batteries will be soon generally armed with the 12-ton 300-pounder, and on important points with 25-ton 600-pounders.

Batteries for mortars, flanked, however, by a few heavy guns, are requisite on certain important points. That of Puckpool, commanding one of the eastern entrances to Spithead, is a formidable battery of this artillery arm, mounting thirty 13-in. mortars.

Each description of gun should have a separate expense magazine for its ammunition.

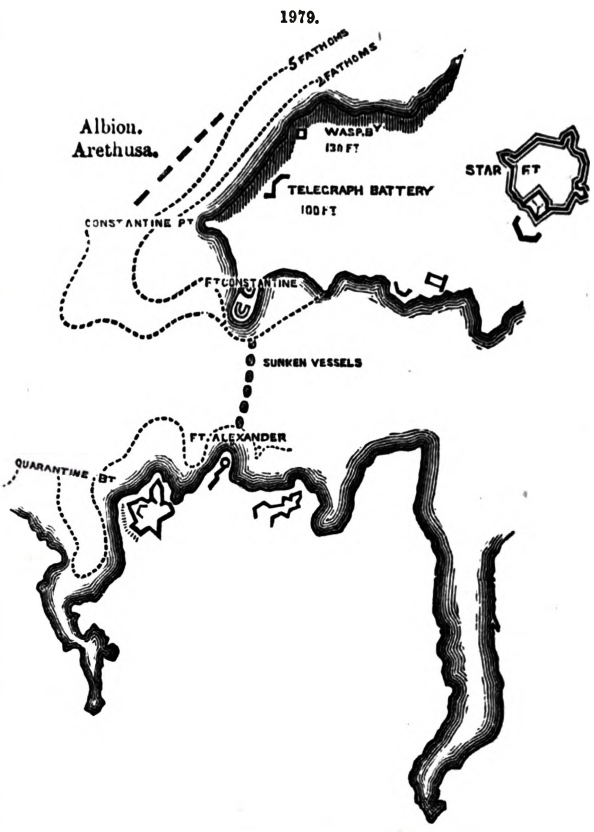
Low barbette batteries should never be used when the work is at less elevation than 100 ft. above the sea-level, and then only they are safe from enfilade.

Barbette batteries have the advantage of a more extended range of fire than those with embrasures.

If a battery be less elevated, the parapet must be heightened, and the gun then fires through an embrasure, or it must be raised, when great range is required, to fire over a parapet of 7 ft. protected by bonnettes.

In earthen batteries the distance between the guns must not be less than 35 ft. when mounted on traversing platforms, and traverses should be provided for every two guns. In casemated and iron-plated batteries the guns are generally spaced 24 ft. from centre to centre, = to a 12-ft. pier and a 12-ft. shield.

Casemated batteries are necessary when it is required to place a work close to deep water, and more than one tier of guns is necessary to defend the position.




All coast batteries, whether casemated or not, should be retired as much as possible from deep water, unless by doing so the object of the battery might not be attained.

We in many cases utilize our casemates both in coast and land batteries by using them as barracks for the garrison, but all partitions and rear walls should be made movable and as slight as possible. Continental coast batteries, when casemated, are generally open in the rear; in double-tier casemated batteries the magazines and stores are usually placed in the basement story, which is faced with solid walls of great strength, and covered with bomb-proof arches.

It is almost useless to discuss here the question of embrasures. Modern science, however, plainly points to the adoption of wrought-iron shields both for casemated and earthen batteries when the Moncrieff system of gun-carriage is not used. The thickness of the shields may vary according to exposure from 9 to 15 in., with the aperture for the gun's mouth as small as practicable.

Red-hot shot or shells filled with molten iron requiring a supply of furnaces and fuel to heat same, were until lately part of the equipment of every coast battery of importance. The universal adoption of iron-clad vessels has however diminished very much the importance of this mode of defence, and our best modern coast forts have no appliances of any kind for heating shot or melting iron except in very peculiar circumstances; an enemy, however, attempting a landing with a flotilla of wooden boats, might suffer severely from the use of heated shot.

The following additional observations are principally founded on Sir J. Burgoyne's 'Notes on the Coast Defences of Great Britain.'

In all arched vaults, such as casemates liable to be battered, the covering arches should be brought endways to the front, so as to form a revetment en décharge.

Batteries or brigades of guns to be brought up with troops to parts of a coast threatened, will be worthy of being organized in time of war in central secure stations.

The most effective fire against ships is doubtless from guns placed but little above the level of the water, but so placed they would be subjected to an overwhelming fire from ships in return.

In proportion as batteries are elevated they lose in the best effect of their own fire, but become far less exposed to suffer from that of ships.

There is also from elevated batteries, if close to the water, a certain space near them which they cannot command at all, and where vessels and boats would be consequently safe from them.

Sir J. Burgoyne considers an elevation of not less than 50 ft. as a good medium elevation: at that height the shot may be made to strike the water at a distance of 200 yds., and will ricochet well, and at the same time the guns would be but little exposed to direct fire from shipping.

Rockets may be of great service in close quarters with ships. With reference to the exposure of guns and gunners, he remarks that in military operations the first aim is to obtain success;

to save life is a secondary consideration, excepting so far as may not impede the first, when of course it becomes an anxious and imperative duty.

He recommends the construction of packets and mercantile steamboats to carry guns in case of need, and the organization of the population of the coast, the coastguard and dockyard men to man our batteries.

The experiences taught in the last American war have thrown quite a new light on what we, a few years ago, learned in the Baltic and the Black Seas. Von Scheliha, in his work on 'Coast Defences,' lays down some general rules, which we here give, being worthy of consideration, and supporting his propositions by examples of different conflicts on the coasts and rivers of America, premising that he considers the Confederates in the first place committed a great mistake in attempting to fortify so many points as they did both on their coasts and rivers.

*a.* That railway communication with different points is preferable to fortifying places of secondary importance.

*b.* That exposed masonry or brickwork is not capable of withstanding the effect of modern artillery.

*c.* That earth, especially sand works properly constructed constitute a better protection against modern artillery than permanent fortifications built on the old plan.

*d.* That guns mounted en barbette, even when protected by properly-built traverses, may be silenced by a concentrated fire from ships.

*e.* No fort now built can keep out a large fleet unless the channel be obstructed.

*f.* A mere partial obstruction of a channel not sufficient to keep out a large fleet.

*g.* No fleet can force a passage if kept under the fire of heavy batteries by properly-placed obstructions.

These views of Von Scheliha are on the whole satisfactory to us with a few exceptions, when we consider the vast outlay we have made within the last few years on our coast defences. With torpedoes and other hidden obstructions, backed by the fire of our modern forts, no fleet could possibly pass narrow channels like that between Hurst Castle and Sconce Point, or the winding sinuosities of deep water between the Spithead Forts, the Thames, Medway, entrance to Plymouth Sound, and other similar localities leading to our principal arsenals and dockyards, as well as the river entrances to our great commercial emporiums, as Liverpool, Hull, Bristol, &c.

The vast alterations in the armaments even of our older defences have rendered a great number of additions to our magazine and store accommodation necessary; increased provision must be made for shells, apparatus for large guns, and so on. In the larger earthen coast batteries the magazines are generally in the rear of the work (which should have its gorge closed by a defensible loop-holed wall), and constructed with bomb-proof arched brickwork, with a covering of earth varying from 4 to 6 ft.; smaller expense magazines are formed in the various traverses, and other secure places in the earth-works. There is considerable difficulty in this climate in preserving these magazines free from damp, principally arising from condensation of saturated air on the walls. If deeply seated in or covered with earth, the ventilation is often defective, and where wooden floors are used considerable ravages have been made by dry rot, the warm and damp air within the magazines appearing to favour the growth of fungi in the timber. Floors of asphalte laid pure without grit are now used in magazines with advantage, and the application of steam in drying the internal air of magazines is a subject worthy of consideration.

The views of Rear-Admiral Porter, U.S.N., on coast and river defences, as enumerated in his report, 1865, are these, namely:—

*a.* Too much importance cannot be attached to the employment of torpedoes and other hidden obstacles.

*b.* Considers that no forts can withstand the united fire of monitors and iron-clad vessels.

*c.* Recommends the combination of military with naval attacks. These formed an important feature too much overlooked, perhaps, in the attack and defence of coast forts during the American war, as at Charlestown Harbour, Vicksburg, &c.

*d.* Little difficulty occurs in running past the strongest forts if no obstructions natural or artificial exist, but on forts only no safe reliance can be placed.

*e.* He knows no instance in which troops and ships properly combined have attacked a fort but they have taken it.

*f.* One gun on shore being considered equal to ten afloat is a principle not at all to be depended on.

*g.* Even if guns in a land battery are protected by traverses they are not safe from vertical fire.

*h.* It must, however, be allowed that there are certain points on every coast where forts can be built unassailable by ships, and that Federal Point, Wilmington River, where Fort Fisher stands, is one of them; also if the engineer who built the latter had placed it one mile inside of where it now stands it would have been inaccessible both by sea and land.

*i.* Guns placed in a land battery should not be less than from 60 to 100 ft. apart.

*j.* Our frowning stone walls with their guns standing en barbette, or looking through small ports in the casemates, look strong, while both arrangements are serious defects.

*k.* Latterly the rebels revetted the stone walls of their forts, external as well as internal, with sand bags.

*l.* Fort Fisher was the key to all the immense system of defences to Wilmington Harbour, and will furnish food for study to our military engineers for years to come; and in many cases the system inaugurated by the rebels will be adopted by us.

*m.* Never erect a fort without consulting the hydrography of its approaches. In Wilmington River a chain of the strongest works ever erected was lost because Fort Fisher, the key to them all, was placed within reach of ships.

*n.* The shells of navy guns most effective against land batteries.

*o.* He recommends that all our works shall be of earthwork, or that those now built should be covered with earth; the guns to be mounted on monitor turrets; iron to any thickness and guns of any measure may be thus used, and so far have an advantage against a floating enemy, in which the use must be limited.

*p.* The value of land fortifications is, he considers, not in the least diminished by the late results; their importance is greater than ever, but they must be properly built.

Fig. 1980 shows the position of Fort Fisher at entrance to Wilmington River.

Fig. 1981, plan of the defences of Fort Fisher.

*Classification of Coast Defences.*—The sea defences of our naval arsenals, commercial harbours, and most accessible landing points on our coasts, may be classified as follows:—

1. Existing old castles erected originally in the times of the Tudors and Stuarts, many of them still forming the nuclei of our present works.

2. Coast towers, martello towers, &c., of more modern construction, dating principally from the period of the earlier wars of the French Revolution.

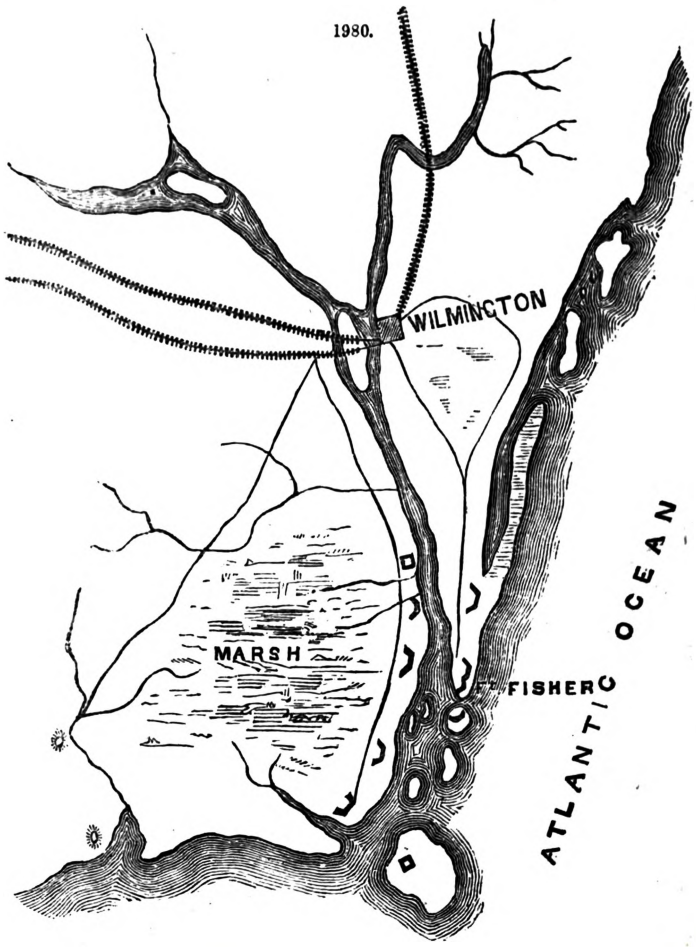
3. Simple earthen batteries firing through embrasures or en barbette, in many cases open or undefended at gorge.

4. Earthen batteries of improved formation, with closed defensible gorge, provided with iron shields to embrasures, and permanent accommodation for gunners, magazines, &c.

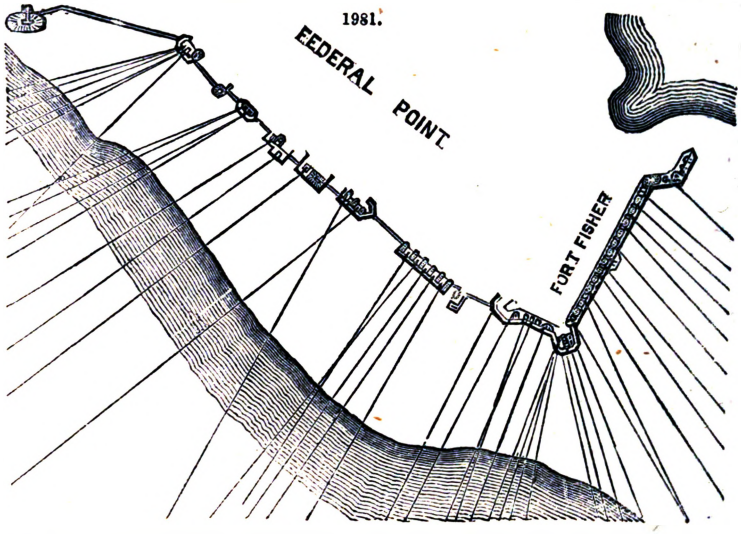
5. Double or single tier casemated composite batteries, with granite facings, iron shields, and defensible keeps and other works at rear.

6. Iron-plated sea forts, in many cases isolated, but covered with iron wherever exposed to shot from direct fire of floating armaments.

1980.




1981.



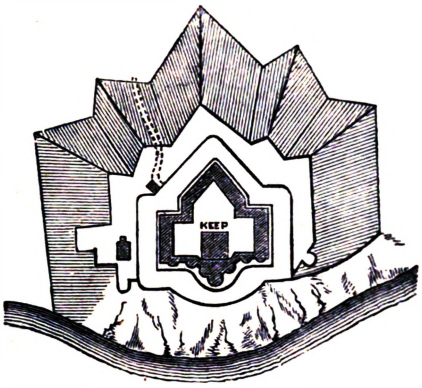

In this classification we have not included numerous coast forts similar to class No. 5, constructed on the old principles of unprotected embrasures, with walls of brick or similar materials, in some cases faced insufficiently with stone. Such is Fort Victoria and Cliff End Fort, on the right-hand side of the Solent passage, the batteries at the entrance to Portsmouth Harbour, and numerous other old though costly forts of the same construction, which must be considered to all intents and purposes obsolete, and should be reconstructed sooner or later, in one of the classes we have given above. This applies to defences constructed by Russia, France, America, Spain,

Holland, and other Powers, as well as by our own Government, during the last couple of centuries, when the principles of Vauban and Coehorn were perhaps more considered in theory than the advantages of site, local marine difficulties, &c., which to-day afford room for the display of the peculiar talents in coast defence by our modern officers of engineers.

*Class* 1.—Previous to Henry VIII.'s time we had, on many points of our coast, castles in the feudal style, such as at Dover, Scarborough, Bamborough in Northumberland, and many others, erected, however, before the invention of artillery. Many of them were allowed to fall to decay when that important element began to come into operation, and the earliest improved form of coast defence appears in the many castles erected by Henry VIII. in dread of an invasion by the Catholic Powers of Europe after his quarrel with the Pope. They consisted generally of a central keep, with curved casemated batteries at a lower elevation, and were constructed of strong and substantial masonry or brickwork, available for store and barrack purposes to the present day. The castles of Southsea, Hurst, Yarmouth, and those of Falmouth and Dartmouth Harbours, Deal, and Walmer, are of this period.

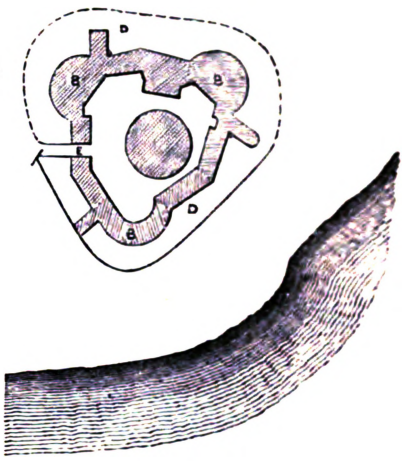
Fig. 1982 shows Southsea Castle as originally built.

1982.




Scale, 12½″ to a mile.

1983.

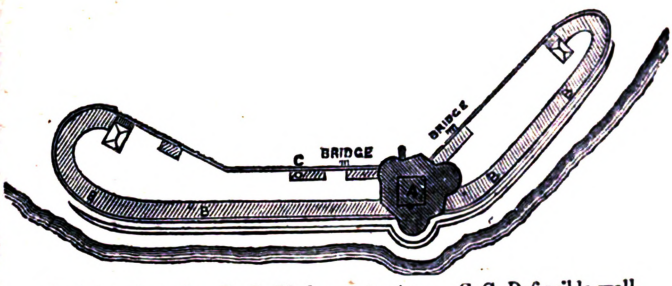



A, Keep. B, B, Batteries. D, D, Ditch.

Fig. 1983 shows Hurst Castle, once the prison of the first Charles. It is now a place of much strength, large casemated granite batteries, same as class No. 5, mounting sixty-one heavy guns, being erected in front and on each flank of the original castle, and showing that the engineers of Henry VIII. had a good eye for a site for defence. Besides these heavy guns, it will probably be eventually equipped with an armament of three turrets on the upper platform, mounting six additional guns, certainly not less than 600-pounders each.

Fig. 1984 shows the modern extensions to the old Hurst Castle.

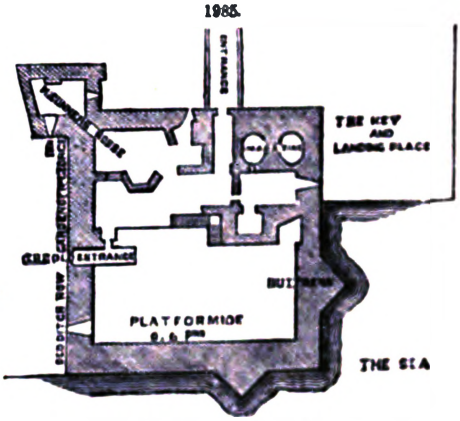
1984.




A, Original work. B, B, Modern extensions. C, C, Defensible wall in rear.

Scale, 300 ft. to an in.

1985.




Scale, 48 ft. to an in.

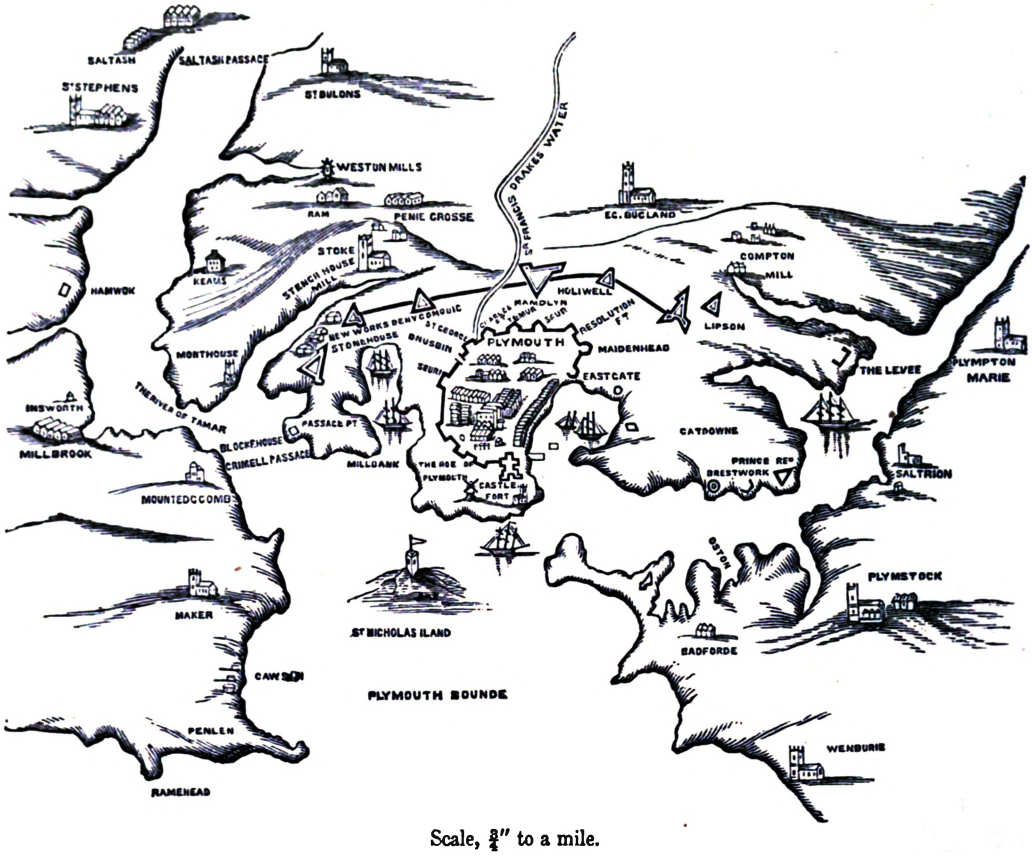
Fig. 1985 shows the old castle of Yarmouth, still mounting half a dozen light guns, and affording accommodation for a few stores and gunners. This is a curious relic of mediæval times, although as a work of defence it is now obsolete and rendered useless by the more modern works in its immediate neighbourhood at Fort Victoria and Cliff End.

The old works at Dover and Sheerness of this period are quite absorbed by the modern works of defence surrounding them. The still-existing important coast work at Landguard Point, mounting twenty heavy guns, has been a good deal modernized, but dates from the time of

James I. The old defences of the sea entrance to Portsmouth and Plymouth Harbours are principally of the Stuart period.

Fig. 1986 shows a bird's-eye view of the defences of Plymouth, land and sea, anno 1643.

1986.




Scale, $\frac{3}{4}$" to a mile.

*Class* 2.—In the early part of the revolutionary war the damage inflicted on one of our ships of the line and a frigate by a single-gun tower in Martello Bay, in Corsica, caused rather an exaggerated idea to be formed of its power of defence, and numbers of them were erected on our southern and eastern coasts, as well as on the weakest points of the Channel Islands, on the coast of Ireland, in the vicinity of Dublin, Cork, and Lough Swilly, &c. Rear-Admiral Porter, in 'Von Scheliha,' reports a similar case where a one-gun, 24-pounder tower, cut up and repulsed a 20-gun frigate that he served in.

Sir J. Burgoyne considers towers may be usefully applied in detached positions, and no doubt, if properly covered by an earthen envelope, would still be found of advantage in defending our coasts in minor operations, or in groups of four to six opposing the landing of an enemy during a period of war, on many points of the 300 miles of shore accessible for landing troops of the 800 miles extending from the Humber to Penzance.

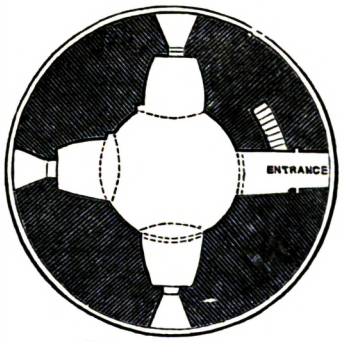
Martello towers were nearly all built on the same model, in England of brick, and in Ireland and the Channel Islands of granite. They generally mount a 24-pounder gun on top, are loop-holed more or less, and accommodate a garrison of from six to twelve gunners. In some cases they are surrounded by a ditch with small bridge, and covered by a glacis; in other cases are merely accessible by a ladder, movable and defended by a machicoulis. Few of those towers are now equipped, and they are generally occupied by a few coastguard men.

Figs. 1987 to 1989, from 'Von Wurmbs,' show the plans and section of a martello tower, the stores and ammunition being kept in the basement. The outer walls are generally from 6 to 8 ft. in thickness.

Figs. 1990 to 1992 show one of the series of towers of the same nature approved by the first Napoleon for coast defence purposes. They are generally square instead of round, and accommodate a larger garrison and mount more guns. They were intended for the same purposes as our smaller towers. On many land frontiers where a small garrison has to hold out against numerous assailants unprovided with heavy guns, such as those of New Zealand and the Cape, these towers would be found very useful, and on the frontiers of the latter colony several of them have been erected. They should, however, be carefully furnished in this case with tanks or wells.

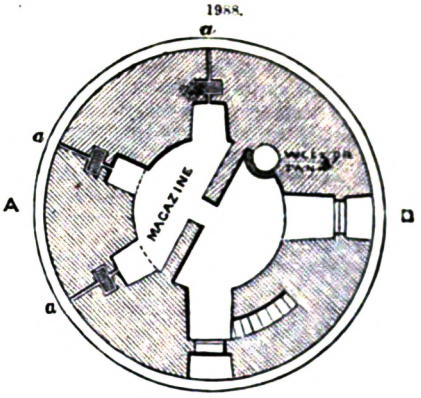
*Class* 3.—*Earthen Batteries undefended at Rear or open at Gorge.*—On many points of the coast elevated from 100 to 300 ft. above high-water mark these batteries will be found economical in construction, and effective. Our experience in the Crimea, which we have already alluded to, where, on the 17th October, 1854, the Allied fleets attacked the outer defences of Sebastopol

1987.



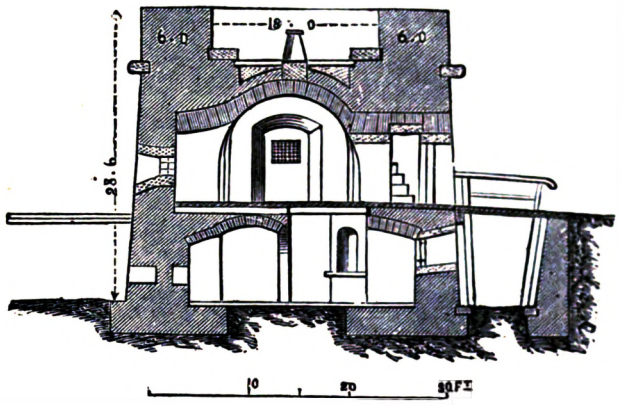

Plan of upper floor.

1988.



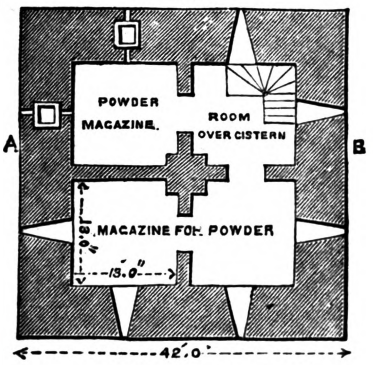

Plan of basement.

1989.



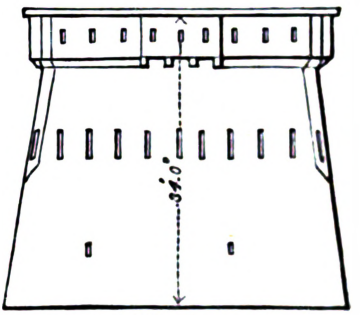

Section on line A B.

1990.



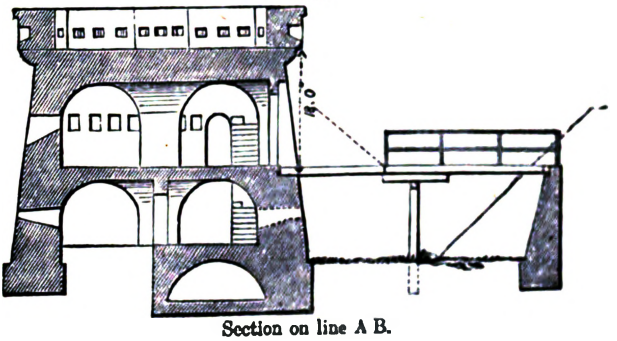

lan.

1991.




Elevation.

1992.



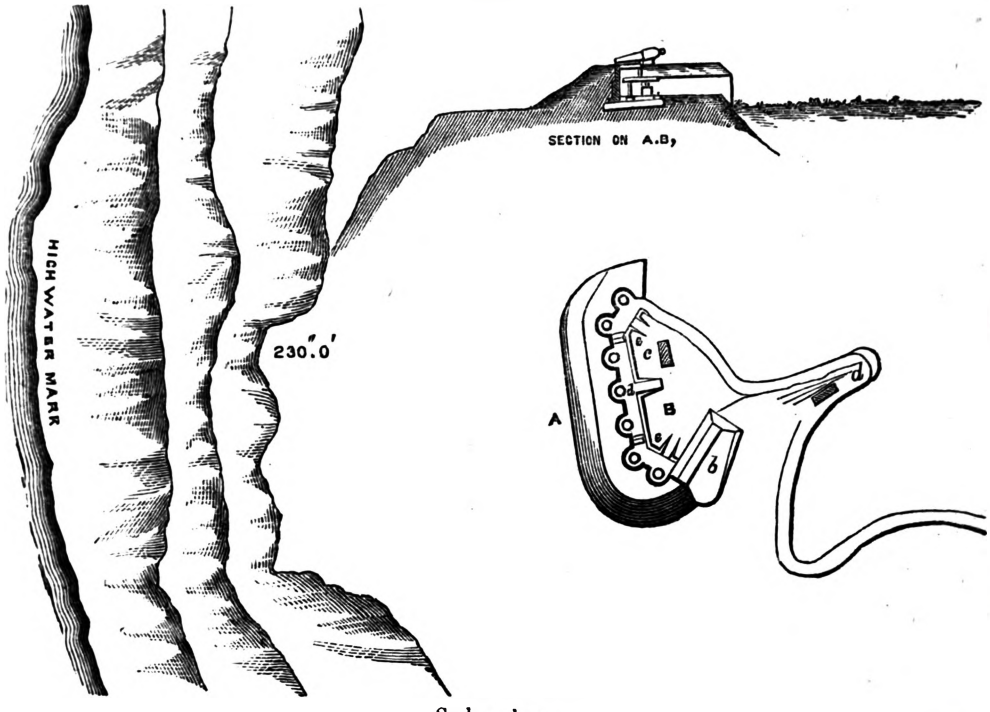

Section on line A B.

Harbour, and the warm reception our heavy-armed ships met from the guns of the little Wasp and Telegraph cliff batteries, which inflicted more damage on them than all the guns of the granite casemated forts put together, will render even iron-clads cautious how they approach those elevated batteries, capable as they are now of being armed with guns of the heaviest calibre. Batteries of this nature in time of war would be supported and supplied by magazines and depôts situated inland, and easily accessible by tram-roads or otherwise.

Earthen batteries may, at an emergency, be easily thrown up, and by the use of strong timber-framing and earth even mount a second tier of guns. Many of the Confederate batteries during the late American war were of this construction; but the materials they are composed of should be always at hand, and therefore they are inapplicable on rocky cliffs, shingly beaches, and similar sites.

Fig. 1993 shows a cheap earthen battery open at rear for seven guns of any calibre up to 300 lbs., the cost of which with bomb-proof magazines, traverses, &c., will not exceed 800*l.* a gun. It is similar to a very excellent battery lately constructed on Hatherwood Cliff, near the Needles, in the Isle of Wight.

1993.

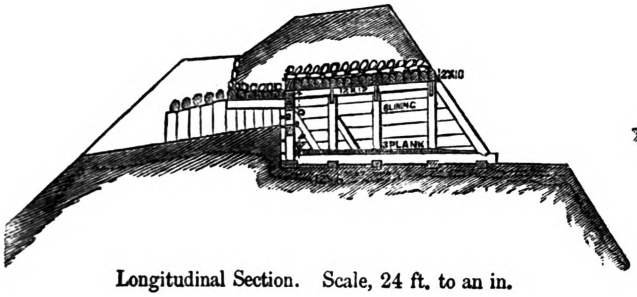



Scale, $\frac{1}{2500}$.

*a*, Terre-plein. *b*, Magazine. *c*, Arm-shed. *d*, Gunners' quarters. *e*, *e*, Traverses.

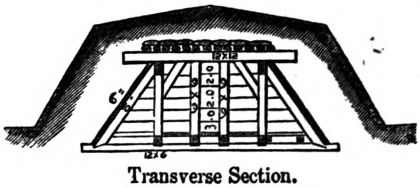
Figs. 1994, 1995, show sections of an earthen battery covering a strong wood framing, forming casemate below, similar to many erected by the Confederates during the American war.

1994.




Longitudinal Section. Scale, 24 ft. to an in.

1995.



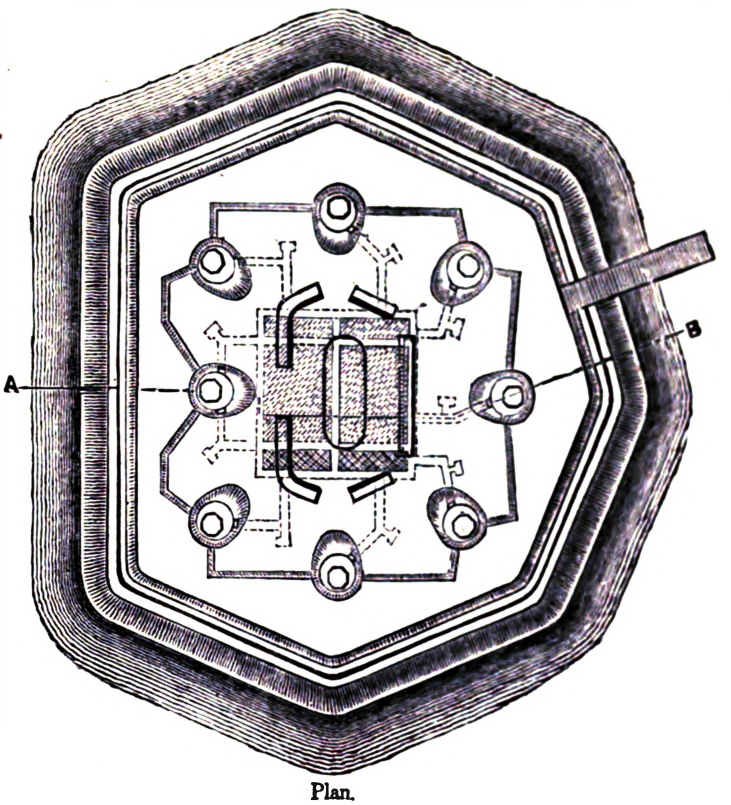

Transverse Section.

Figs. 1996, 1997, plan and section of Fort Powell, in Mobile Harbour, a combination of earthwork and timber.

*Class* 4.—*Earthen Batteries, with Accommodation in Rear for Troops and Stores, &c., with closed Loop-holed Gorge and enfiladed Ditches in Front and on Flanks.*—Mounted with heavy guns, batteries of this nature are a most useful element of defence for our commercial harbours, and the rivers leading to our principal maritime emporiums, &c. They are constructed generally on the most commanding positions and have ample accommodation, in low flat-roofed buildings, for their garrison

in the rear, and well-protected bomb-proofs for magazines and stores, wells and water-tanks, so as to be enabled to resist a *coup-de-main*, if the enemy should land a force in their neighbourhood. The guns, which may be of the heaviest calibre, fire either en barbette or through earthen embrasures protected with iron shields. The ditch in front and on flanks is often further defended by a loop-holed Carnot-wall and flanking caponnière chambers. Of this class are batteries lately erected to protect the channel of the Humber, the entrance to the Orwell and Stour rivers near Harwich, the new batteries on each flank of Southsea Castle, and various other points on the coast. Moncrieff gun-pits will be equally applicable to batteries of this construction as the last; ample shelter for gunners is provided in the interior of traverses, passages to magazines, &c. These batteries in connection with floating or hidden obstructions would make the approach to our principal maritime towns, situated a few miles inland, nearly impossible; the gunners also enjoying good quarters, not subject to the inconvenience or dangers of casemated batteries.

1996.




Plan.

1997.

Section on line A B.

In the construction of batteries of this description the immensely increased penetrating power of modern artillery on earth-works must be taken into consideration. The penetration of a 600-lb. shot fired from a 13-in. gun at 200 yards is estimated at 50 ft., and a 150-lb. 9-in. shot at the same distance, 30 ft.

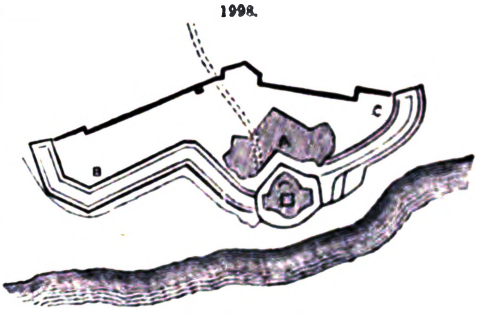
Fig. 1998 shows Southsea Castle, with auxiliary earthen batteries and defensible gorge-wall in rear.

Figs. 1999 to 2001 show a 2-gun battery similar to those on the Humber and near Harwich, with Carnot-wall in ditch, soldiers' quarters, and stores in rear. The unit for such batteries may be considered the distance from centre to centre of each gun mounted, or generally from 35 to 40 ft. American engineers consider this distance ought to be enlarged.

Earthen batteries are sometimes armed with mortars which will make, where they are mounted, a different arrangement necessary.

Figs. 2002, 2003, show a unit of a mortar battery containing platforms of from four to six mortars in a group. These may be placed in the most eligible positions for vertical fire, and the remainder of the battery armed with heavy guns.

1998.

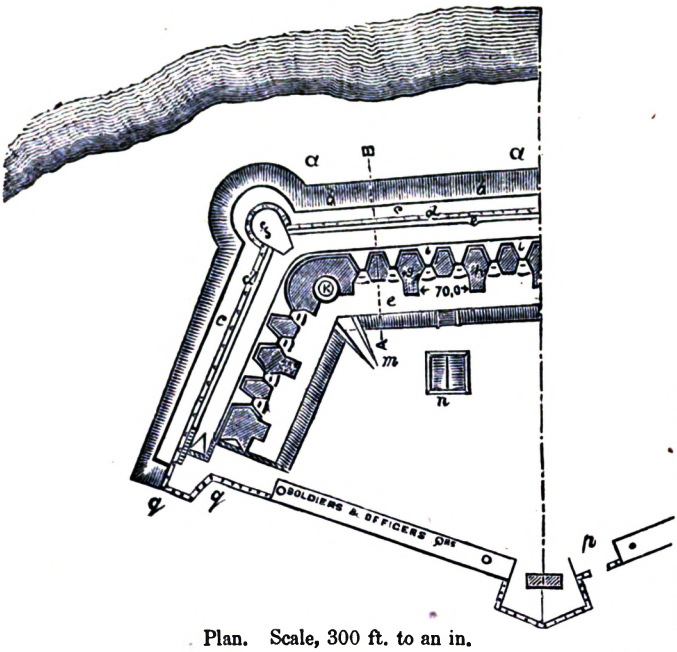



Scale, 6" to a mile.

A, Old Central Work. B, New West Battery. C, New East Battery

*Class* 5.—*Single or Double Tier Casemated Batteries, faced with Granite and provided with Iron Shields to Embrasures.*—When the Defence Commission of 1860 made their report, granite-faced casemated batteries, from the experience the then unarmoured ships had received in the Baltic and the Crimea, were in high favour; it was then a question of granite *versus* oak, not as now granite *versus* iron; and in the representations in the pictorial papers of the day, the granite forts

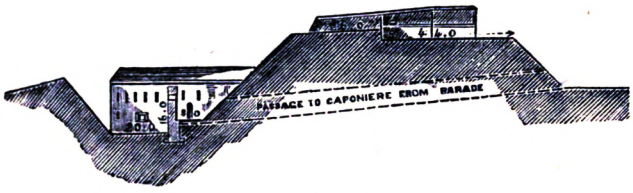
1999.




Plan. Scale, 300 ft. to an in.

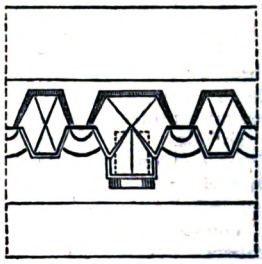
*References:*—*a*, *a*, Glacis. *b*, *b*, Slope of ditch. *c*, *c*, Ditch. *d*, *d*, Carnot-wall. *e*, *e*, Banquette. *f*, Caponnière. *g*, *g*, Traverses. *h*, *h*, Expense magazine. *i*, *i*, Embrasures. *k*, Gun en barbette. *l*, Terre-plein. *m*, Parade. *n*, Magazine. *o*, Quarters in rear. *p*, Entrance. *q*, *q*, Defensible gorge-wall.

2000.



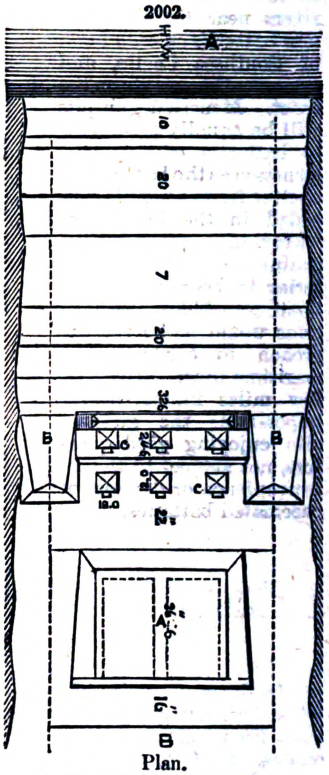

Section on line A B.

2001.



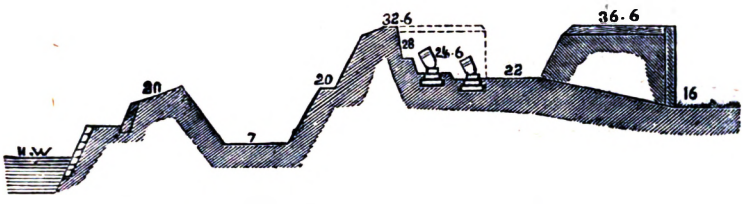
Unit showing two guns and traverses.
Scale, 100 ft. to an in.

2002.




Plan.
A, Magazine. B, Traverses.
C, Mortar beds.

2003.



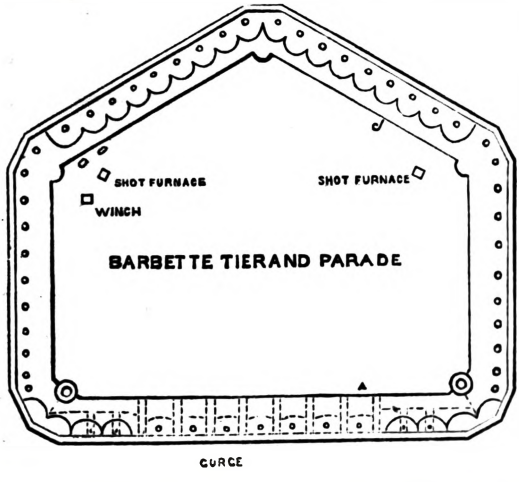

Section on line A′ B′. Figures show height above high water.

of Cronstadt and Sebastopol presented a most threatening and formidable appearance. Those of Cronstadt had defied our attacks, because, as military critics say, they were never made; and in the little tussle between the Allied fleets and the Sebastopol batteries it must be confessed that we stood in considerable awe of them, and kept, with one or two exceptions, at a most respectful distance, and when we did approach nearer got the worst of it. The destruction of the Bomarsund defences would naturally be attributed to their unfinished state, as well as to the co-operation of a land attack; therefore the Defence Commission were rather inclined to look with favour on granite walls and embrasures, even when unprovided with iron shields or platings; and we find our most important and expensive works were proposed to be executed in that material, and,

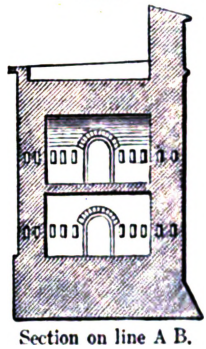
with the (in the course of time) necessary alterations and additions for iron shields to embrasures, have been so constructed. We may instance—the Garrison Point and Isle of Grain defences, near Sheerness; the Thames and Medway forts; the important position of Gillkicker and Hurst Castle in the Spithead and Solent defences of Portsmouth Harbour; many works also in the Plymouth and Milford Haven defences. But more recent experience has shown us, in batteries at the water-level, or only moderately elevated above the same, even when furnished with iron shields to embrasures, that solid stone piers offer but a poor resistance to the heavy guns of modern warfare. Unfortunately, many of our forts were already thus built before the experience of the late American war was acquired; and to plate them with iron now would cost nearly as much as their original construction; and, indeed, in many cases when they are retired from the water's edge would not be necessary. It is, however, probable that for the future granite will enter much less into our coast defences as an element of resistance than it has hitherto done. An inspection of the diagram we give, of a granite-faced iron-embrasured coast battery, Figs. 2014, 2015, shows a rather defective construction, for if the intermediate piers be battered down, the abutments of the groined arches necessary for the movement of the guns within will be destroyed, and the whole of the bomb-proof masonry and guns on terre-plein above will become a heap of ruins. The attention of our engineers is now directed to a simpler mode of construction, in which wrought-iron girders and iron-buckled plates covered with concrete and earth will probably supersede brick arches altogether, unless in cases where the end of the arch itself goes through the external walls, and direct fire will not affect its stability. Batteries of this nature are composed of units, the unit being a casemate for one gun; a battery of any number of guns therefore consists of as many units arranged in as many tiers as may seem desirable. The store and magazine accommodation is generally in the basement, where the external walls are solid, and of great thickness, and it will be necessary to provide for at least 200 rounds of shot and shell for each gun, besides all necessary tramways, lifts, &c., for the easy conveyance of the heavy missiles we now use, and the fall of one of which might endanger the safety of the whole battery. These magazines are lighted by oil lamps, with thick plate-glass fronts and reflectors, and fixed through apertures in the external walls. In many cases during the late American war it was found necessary to revet stone-faced batteries with sand-bags.

Figs. 2004 to 2006 are a plan and sections of Fort Sumter, which after a long resistance was finally destroyed by the Federal American fleet. It is not a favourable example of a casemated battery, as the casemates are small and confined, and the thickness of the walls appears insufficient.

2004.

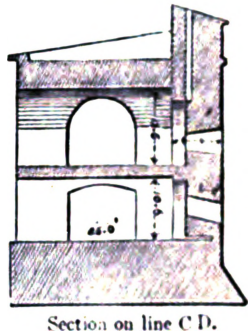



2005.



Section on line A B.

2006.



Section on line C D.

Figs. 2007, 2008, show plan and sections of the unit of a single-tier casemated battery. Turret guns or heavy guns en barbette may be mounted on top. In this case the magazines are detached and not in basement.

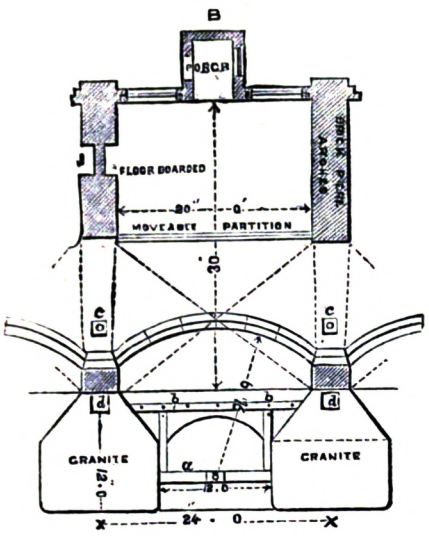
Figs. 2009 to 2011 are a coast battery, with a small keep in rear, mounting thirteen guns in casemates and eight heavy rifled guns on terre-plein, from Von Wurmbs' 'Lehrbuch der Kriegs Baukunst.'

Figs. 2012, 2013, show two casemates of the old Blockhouse Battery at the entrance to Portsmouth Harbour, and section through same. The limited dimensions of the casemates are a great contrast to those of the present day, although with the old guns this battery was considered a most efficient one.

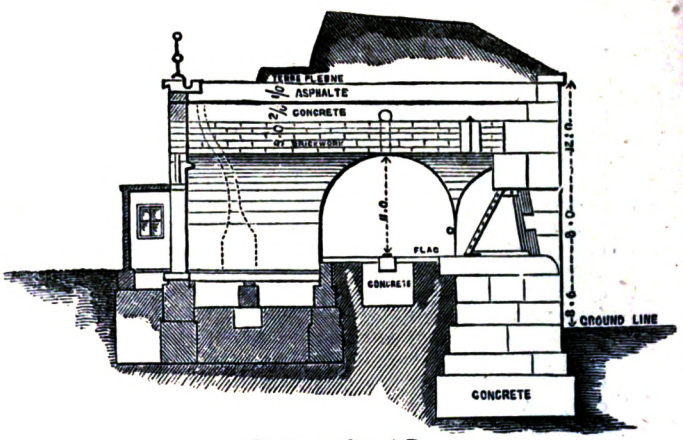
Figs. 2014, 2015, show an example of one of the most approved single or double tier casemated battery, with magazine and stores beneath, and casemates fitted to accommodate troops, with verandah behind. Before the adoption of iron external plating, these batteries were probably the strongest construction used. Their cost, including the shields, buildings, and wall in rear, would be about 3500*l.* a gun. This construction is applicable to any portion of a curved surface, or to the entire circle.

Many of the batteries of the Russian arsenals, and those of France and the United States, are formed on this principle, which we are beginning reluctantly to consider obsolete. Russia and other countries have already commenced plating their granite batteries with iron. We fear,

2007.

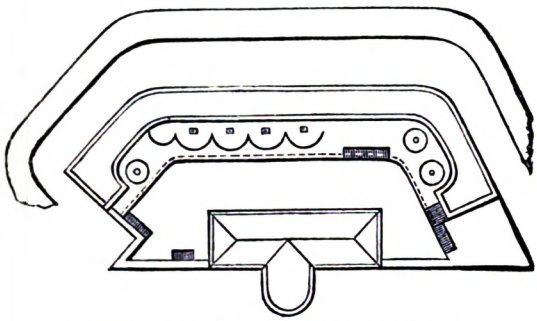



2008.



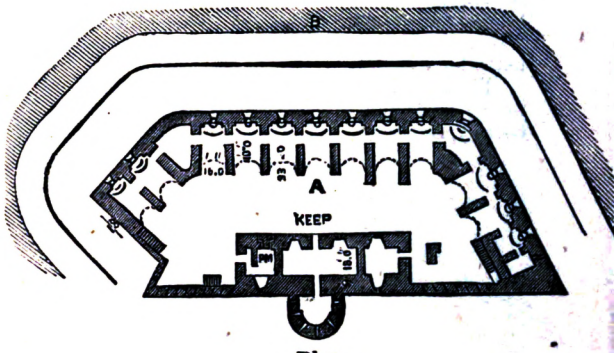

Section on line A B.

2009.



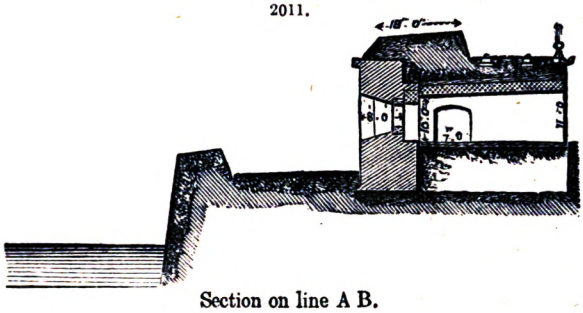
Plan of Terre-plein. Scale, 100 ft. to $\frac{3}{4}$ in.

2010.



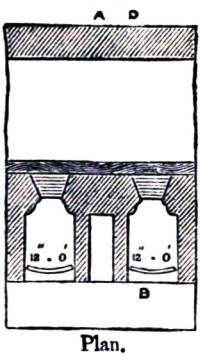

Plan.

2011.



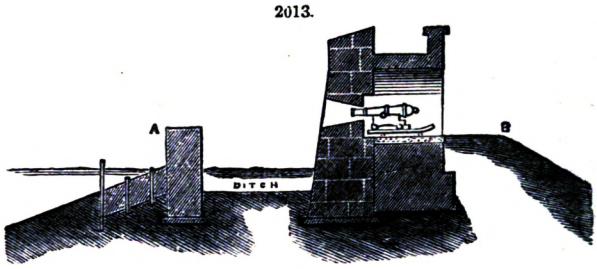
Section on line A B.

2012.




Plan.
Scale, 48 ft. to an in.

2013.

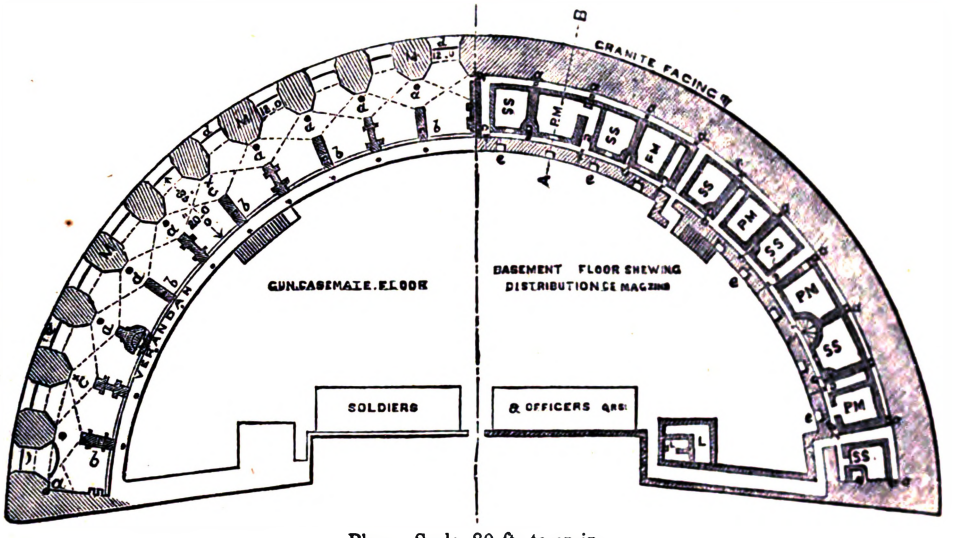



Section on line A B.

however, that total reconstruction will be in many cases found necessary, as it was with our men-of-war a few years ago.

*Class* 6.—*Iron-clad isolated Forts plated on Stone Walls, or independent Iron Constructions.*—There are in progress now the stone bases of four marine forts, 200 ft. diameter, at Spithead, and one of an elliptical shape, but nearly of the same mean dimensions, on the Shovel Rock, behind the Plymouth Breakwater. Recent experiments at Shoeburyness would seem to point out that the resisting face or iron construction of these forts should be quite unconnected with, and independent of, the internal arrangements of masonry or brickwork, forming, as it were, an external shell round same. The plating of granite walls with iron plates, connected by heavy bolts and screws, we have always considered to be a mistake, as the elasticity and continuity of material which might permit it on the wooden sides of ships are much wanting either on walls of granite or brick. The Russians are attempting a sort of plating on their Cronstadt forts; but practical men doubt of its ever being effective, and the expense of plating walls with railway iron and such small material in the American war led to no satisfactory results when opposed to heavy guns. The internal arrangements of forts of this nature will differ little from those of the casemated granite forts shown in Figs. 2014, 2015.

2014.

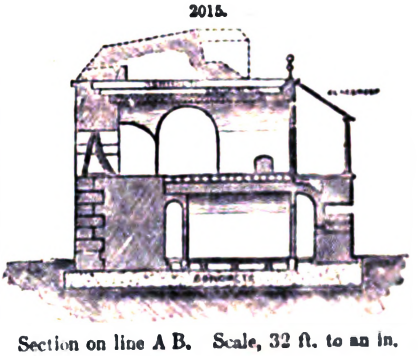



Plan. Scale, 80 ft. to an in.

*References*:—*a*, *a*, Powder lifts. *b*, *b*, Shell lifts. *c*, *c*, Light boxes. *d*, *d*, Iron shields. *e*, *e*, Ventilating and light apertures. M, Stone piers. P, M, Powder magazines. S, S, Shot and shell store. L, Laboratory. N, Terre-plein.

Sir J. F. Burgoyne, in his letters to the Secretary of State with reference to the defence works, dated 20th February, 1867, observes:—"The circumstances under which it is most requisite to apply iron defences on the fullest scale are where batteries are necessarily placed in very exposed and isolated situations, and where the area of the site on which guns can be placed is unavoidably restricted; such as in the sea or in a very few analogous positions on shore, where foundations are costly and where the works are subject to a concentrated fire from a large number of powerful iron-plated men-of-war.

2015.



Section on line A B. Scale, 32 ft. to an in.

"On the shore where the space is not limited and where guns are more or less dispersed, or in channels where there is no probability of ships being able to engage batteries for a lengthened period, it is only requisite to apply iron in the form of shields for strengthening that part of the work about the embrasures, which in batteries of an earthen or granite construction would otherwise be very weak. In cases where batteries are at a considerable height above the sea, no embrasures are necessary, and iron shields are not required."

*General Notes on the Practical Construction of Coast Batteries.*—When stone is used in the facing of batteries it should be of the hardest and most compact nature, in as large blocks as possible, and set on its natural bed; even in granites this should be regarded, although they are often erroneously supposed to have none. If intended to be afterwards iron-plated, all the necessary holes for bolts, chases, sinkings, &c., should be previously made. Granite or other stone facing may be backed with brickwork, and the same may be used in all revetments, walls of magazines, &c., not exposed to direct fire.

The greatest care should be taken to ensure ventilation to all floors and other woodwork in earth-covered buildings.

In throwing up earthen batteries of any size, the engineer should study the geological peculiarities of the site, nature of the formations, &c. Many serious failures in our earth-works have occurred by the neglect of this precaution, especially near the junction of the chalk and tertiary formations, and in the various drift deposits on our southern coasts.

When earth-works are to be thrown up, the proper drainage of the natural surface beneath them should be considered, so as to prevent the accumulation of water in the earth formed as a rampart. This should be a preliminary step, and is too often overlooked, causing constant slips in the slopes formed.

Earth-works should be formed in layers not more than 15 in. in thickness, and well rammed. Occasional thin beds of burnt ballast or shingle should be used, and agricultural drain-pipes so laid as to conduct off all superfluous water as quickly as possible.

Slopes steeper than 45° can hardly be formed without the employment of built sodwork, which experience proves is very liable to decay. Flat slopes may be either covered with flat sods or soiled with fine mould and sown with selected grass seeds, with roots calculated to form a fibrous network.

Conduct all rainfall off your works as rapidly as possible, by means of surface, pipe, or other drainage.

Give your guns plenty of room, and let their platforms or *racer-blocks* be firmly bedded.

If iron plating be used, let its form be simple and with as few bolts as possible, and let all ironwork of embrasures be painted the same tint as the surrounding material, whether grasswork or granite, so as not to present a distinguishing mark at a distance.

Earth-works should be formed as free from shingle or loose stone on the external covering as possible, although in some cases a core of such material may be found convenient to use; one of chalk forms an excellent nucleus for a battery.

The comparative cost of earth, concrete, granite, and iron, in relation to their comparative strength, may be estimated, taking earth as the unit, as 1, 3, 10, 50. Concrete costs 10 times as much as earth, but offers 3 times the resistance; granite 100 times as much, but 10 times the resistance; and iron 40 times as much, but from 2000 to 3000 times the resistance.

Every battery, no matter how small, should be provided with a well or tank for the supply of water.

The position of the flag-staff of a coast battery should be such as to draw off the fire of an enemy to a point where it will do as little harm as possible, as it is often the only target for an enemy to fire at.

Let all artificial lights in magazines, &c., be so placed that no concussion can displace them.

No ventilating shaft or passage should be made which could admit of the direct entrance of any missile into a magazine or passage of same.

And finally, gunners should be made to feel perfect confidence in the stability of the batteries they are appointed to defend, and in the sufficiency of shelter and means of supplying ammunition to the guns, and cover for the wounded.

TABLE I.—SHOWING PROBABLE MAXIMUM PENETRATION OF PROJECTILES IN VARIOUS MATERIALS.
(Appendix to Report of Committee on Fortifications, 1868.)

| Nature of Gun. | Maximum Penetration in | | | | | | Remarks. |
|---|---|---|---|---|---|---|---|
| | Earth. | Concrete. | Brickwork. | Rubble Masonry. | Granite. (a) | Iron Plating.(b) | |
| | ft. | ft. | ft. | ft. | ft. | in. | |
| 12-in. .. .. | 50 | 15 | 15 | 10 | .. | 15 | (a) The destructive effect of a shot in fracturing granite, extends far beyond the limits of actual penetration. (b) The thickness given are those of single plates, which are just capable of keeping out a shot. |
| 10 „ .. .. | 45 | 14 | 14 | 9 | .. | 14 | |
| 9 „ .. .. | 40 | 12 | 12 | 8 | 2 | 11 | |
| 8 „ .. .. | 35 | 11 | 11 | 7 | .. | 10 | |
| 7 „ .. .. | 30 | 9 | 9 | 6 | .. | 9 | |
| 110-pounder .. | 28 | 8 | 8 | 5 | .. | 6 | |
| 70 „ .. | 24 | 7 | 7 | 4 | .. | 5 | |
| 40 „ .. | 16 | 5 | 5 | 3 | .. | 4½ | |
| 20 „ .. | 12 | 4 | 4 | 2 | .. | 4 | |
| 12 „ .. | 5 | 2 | 2 | 1 | .. | 3 | |

TABLE II.—SHOWING PROBABLE MAXIMUM PENETRATION OF SPHERICAL MORTAR-SHELLS IMPINGING WITH THE GREATEST VELOCITY WHICH THEY CAN ACQUIRE IN AIR.

| Nature of Shell. | Maximum Penetration in | | | |
|---|---|---|---|---|
| | Earth. | Concrete. | Brickwork. | Rubble Masonry. |
| | ft. in. | ft. in. | ft. in. | in. |
| 13-in. | 6 0 | 1 6 | 1 6 | 8 |
| 10 „ | 4 0 | 1 0 | 1 0 | 7 |
| 8 „ | 3 0 | 0 8 | 0 8 | 6 |

TABLE III.—SHOWING COVERING FOR BOMB-PROOF CONSTRUCTIONS, SEMICIRCULAR ARCHES, AND ARCHES OF 120°. (Report, 1869.)

| Span. | Covering for Bomb-proof Casemate. | | | | | | Remarks. |
|---|---|---|---|---|---|---|---|
| | Semicircular Arches. | | | Arches of 120°. | | | |
| | Block Stone. | Brick. | Rubble Stone. | Block Stone. | Brick. | Rubble Stone. | |
| ft. | ft. in. | No. | ft. in. | ft. in. | No. | ft. in. | |
| 5 | 0 9 | 1 | 0 11 | 0 10 | 1 | 1 0 | The thicknesses given in this Table for arches are not in themselves adequate to resist the concussion of the fall or explosion of the charge of 13-in. shells. They are calculated in all cases to be protected by a further covering of from 2 to 3 ft. of concrete, or from 4 to 6 ft. of earth. |
| 6 | 0 10 | 1 | 1 0 | 0 11 | 1½ | 1 2 | |
| 8 | 1 0 | 1½ | 1 2 | 1 2 | 1½ | 1 4 | |
| 10 | 1 2 | 1½ | 1 4 | 1 3 | 1½ | 1 6 | |
| 12 | 1 3 | 1½ | 1 6 | 1 4½ | 2 | 1 8 | |
| 14 | 1 4 | 1½ | 1 8 | 1 6 | 2 | 1 10 | |
| 16 | 1 5 | 2 | 1 9 | 1 7 | 2½ | 2 1 | |
| 18 | 1 6 | 2 | 1 10 | 1 8 | 2½ | 2 2 | |
| 20 | 1 7 | 2½ | 1 11 | 1 9 | 3 | 2 4 | |
| 22 | 1 8 | 3½ | 2 2 | 1 10 | 3½ | 2 6 | |
| 24 | 1 9 | 3½ | 2 4 | 2 0 | 4 | 3 0 | |

TABLE IV.—SHOWING WEIGHT AND ENERGY OF GUNS AND PROJECTILES.

| Description of Gun. | Weight of | | | Initial Velocity with Highest Charge. | Energy or Punching Power per Inch of Shot's circumference. | | Total Energy of Projectile at 1000 yds. |
|---|---|---|---|---|---|---|---|
| | Gun. | Projectile. | Highest Charge. | | At Muzzle. | At 1000 yds. | |
| *Cast-iron Smooth Bore.* | tons. cwt. | lbs. | lbs. | ft. | foot-tons. | foot-tons. | foot-tons. |
| 32-pounder .. .. .. | 2 18 | 32 | 10 | 1690 | .. | .. | .. |
| 8-in. shell .. .. .. | 3 5 | 49½ | 10 | 1488 | .. | .. | .. |
| 68-pounder .. .. .. | 4 15 | 68 | 16 | 1579 | 46 | 18 | 452 |
| *Wrought-iron Muzzle-loading Rifles.* | | | | | | | |
| 7-in. .. .. .. .. | 6 10 | 115 | 22 | 1430 | 75 | 52 | 1143 |
| 8 „ .. .. .. .. | 9 0 | 180 | 30 | 1330 | 88 | 66 | 1659 |
| 9 „ .. .. .. .. | 12 0 | 250 | 43 | 1340 | 111 | 85 | 2403 |
| 10 „ .. .. .. .. | 18 0 | 400 | 60 | 1290 | 148 | 123 | 3863 |
| 11 „ .. .. .. .. | 25 0 | 600 | 70 | 1212 | 163 | 137 | 5165 |
| 12 „ .. .. .. .. | 30 19 | 600 | 100 | .. | .. | .. | .. |

The following statements will show the financial position of our defence works from the period of the first report of the committee until 1869.

TABLE A.—ORIGINAL ESTIMATE OF THE DEFENCE COMMISSION OF 1860.

| Place. | Recommendation of Royal Commission. | | Already authorized, but not voted. | Total. |
|---|---|---|---|---|
| | Purchase of Land. | Erection of Works. | | |
| | £. | £. | £ | £ |
| Portsmouth .. .. .. .. | 330,000 | 2,070,000 | 400,000 | 2,800,000 |
| Plymouth .. .. .. .. | 755,000 | 1,915,000 | 350,000 | 3,020,000 |
| Pembroke .. .. .. .. | 150,000 | 450,000 | 165,000 | 765,000 |
| Portland .. .. .. .. | 100,000 | 150,000 | 380,000 | 630,000 |
| Thames .. .. .. .. .. | 50,000 | 180,000 | .. | 180,000 |
| Medway and Sheerness .. | | 400,000 | .. | 450,000 |
| Chatham .. .. .. .. | 180,000 | 1,170,000 | .. | 1,350,000 |
| Woolwich .. .. .. .. | 300,000 | 400,000 | .. | 700,000 |
| Dover .. .. .. .. .. | 20,000 | 150,000 | 165,000 | 335,000 |
| Cork .. .. .. .. .. | .. | 120,000 | .. | 120,000 |
| Armament of works .. .. | .. | .. | .. | 500,000 |
| Floating defences .. .. | .. | .. | .. | 1,000,000 |
| Totals .. .. | 1,885,000 | 7,005,000 | 1,460,000 | 11,850,000 |

When the report of the commission was considered by Government, it was determined to raise the money for works and lands by loan, and to provide for the armaments and floating defences in the annual estimates.

Omitting, therefore, these last two sums (1,500,000*l.*), the commissioners' estimate may be divided thus:—

| | £. |
|---|---|
| For completion of works authorized previous to 1860 .. .. .. | 1,610,000 |
| For new works recommended by the commission, including 1,885,000*l.* for land .. .. .. .. .. .. .. .. .. .. | 8,740,000 |
| Total .. .. .. .. .. .. .. | £10,350,000 |

This amount was, however, in the first instance reduced by Government, by the omission of several important items, namely:—

| | | | |
|---|---|---|---|
| Portsmouth .. | Two Spithead forts and two advanced forts, Gosport position .. .. .. .. .. .. | | 460,000 |
| Plymouth .. | Inner line, N.E. defences, omitted, and reduction in Breakwater Fort .. .. .. .. .. | | 400,000 |
| Pembroke .. | Reduction in number of land-works .. .. .. | | 150,000 |
| Medway .. .. | Grain Spit Fort .. .. .. .. .. .. .. | | 100,000 |
| Woolwich .. | Total amount .. .. .. .. .. .. .. | | 700,000 |
| | | | 8,540,000 |

Government added, however,

| | £. | |
|---|---|---|
| Dover, additional .. .. .. .. .. .. .. .. .. | 30,000 | |
| Central Arsenal (afterwards omitted) .. .. .. .. | 150,000 | |
| | | 180,000 |
| First reduced estimate .. .. .. | | £8,720,000 |

In proposing, however, the first vote to Parliament, further works were omitted, namely:—

| | | £. | £. |
|---|---|---|---|
| Amount proposed by Government .. .. .. .. .. .. .. | | | 8,720,000 |
| Portsmouth .. | Connecting lines .. .. .. .. | 20,000 | |
| Plymouth .. | Part of N.E. defences and the whole of the Saltash .. .. .. .. | 1,800,000 | |
| Chatham .. .. | W. defences .. .. .. .. .. | 700,000 | |
| Pembroke .. | Further reduction in number of land-works .. .. .. .. .. | 250,000 | |
| | | 2,150,000 | |
| And a further reduction for works provided for in A Estimates, 1860-61 .. .. .. .. .. .. | | 390,000 | |
| | | | 2,540,000 |
| Remaining to be provided by loan .. | | | £6,180,000 |

TABLE B.—ESTIMATED EXPENDITURE FOR COMPLETION.

| | | £. | £. |
|---|---|---|---|
| Portsmouth .. | Land defences outer line .. .. | 550,000 | |
| | Land defences inner line .. .. | 320,000 | |
| | Spithead defences .. .. .. .. | 1,387,000 | |
| | Isle of Wight defences .. .. .. | 163,000 | |
| | Needles defences, including Hurst Castle .. .. .. .. .. .. | 261,000 | |
| | | | 2,681,000 |
| Plymouth .. | Harbour defences .. .. .. .. | 455,000 | |
| | Land defences .. .. .. .. | 763,000 | |
| | | | 1,218,000 |
| Pembroke .. | Sea defences .. .. .. .. .. | 265,000 | |
| | Land defences .. .. .. .. | 130,000 | |
| | | | 395,000 |
| Portland .. .. | Verne Citadel .. .. .. .. | 125,000 | |
| | Nothe and Breakwater Batteries | 316,000 | |
| | | | 441,000 |
| Gravesend or Thames defences | Forts at Coalhouse, Cliffe, Shornemeade, and Slough .. .. .. .. .. .. .. .. | | 420,000 |
| | Carried forward .. .. .. .. | | £5,155,000 |

TABLE B.—ESTIMATED EXPENDITURE FOR COMPLETION—*continued.*

| | | £ |
|---|---|---|
| | Brought forward .. .. .. .. | 5,155,000 |
| Medway .. .. | Isle of Grain, Sheerness, Hoo, and Darnet Forts | 435,000 |
| | Sheerness land defences .. .. .. .. .. | 40,000 |
| Chatham .. | East defences .. .. .. .. .. .. | 70,000 |
| Dover .. .. | Castle Hill Fort, Dover Castle, Western Heights | 301,000 |
| Cork .. .. | Spike Island, Carlisle Fort .. .. | 189,000 |
| | | 6,190,000 |
| | Incidental expenses, works, and experiments .. .. .. | 165,000 |
| | Lands, including all legal and surveyors' charges .. .. | 1,115,000 |
| | Total .. .. .. .. .. | £7,470,000 |

And if turrets and turn-tables be provided, as recommended by the Fortification Committee, probably 270,000*l.* in addition.

A further summary of the cost of these works given in the 'Report of the Committee appointed to inquire into the Construction, Cost, &c., of the Fortifications,' 1869, gives a total of .. .. .. .. .. .. .. .. £7,951,437

TABLE C SHOWS THE NUMBER OF HEAVY RIFLED GUNS REQUIRED FOR THE ARMAMENT OF SEA BATTERIES ERECTED, OR IN COURSE OF ERECTION, UNDER THE LOAN FOR DEFENCES.

| Name of Work. | | Description of Gun. | | | |
|---|---|---|---|---|---|
| | | 12" Gun, 25 Tons. | 10" of 18 Tons. | 9" of 12 Tons. | 7" of 6½ Tons. |
| Portsmouth .. | Horse Sand Fort .. .. .. .. .. | 10 | 24 | 25 | .. |
| | No Man's Land Fort .. .. .. .. | 10 | 24 | 25 | .. |
| | Spit Bank Fort .. .. .. .. .. | 4 | 9 | .. | 6 |
| | St. Helen's Fort .. .. .. .. .. | 4 | 6 | .. | 4 |
| | *Puckpool Battery .. .. .. .. | 4 | .. | .. | .. |
| | Hatherwood Battery .. .. .. .. | .. | .. | 4 | 3 |
| | Warden Point .. .. .. .. .. | .. | .. | 4 | 4 |
| | Cliff End Batteries .. .. .. .. | .. | .. | 20 | .. |
| | Sandown Fort .. .. .. .. .. | .. | .. | 18 | 10 |
| | Southsea Batteries .. .. .. .. | 1 | .. | 22 | 9 |
| | Gillkicker Battery .. .. .. .. | 5 | 17 | 5 | .. |
| | †Hurst Castle .. .. .. .. .. | 6 | .. | 61 | .. |
| | Needles .. .. .. .. .. .. .. | .. | .. | 2 | 4 |
| Plymouth .. | Bovisand Battery .. .. .. .. .. | .. | 14 | 9 | .. |
| | Plymouth Breakwater Fort .. .. | 4 | 18 | .. | .. |
| | Picklecombe Battery .. .. .. .. | .. | 19 | 19 | 4 |
| | Mount Edgcumbe Battery .. .. .. | .. | .. | 7 | .. |
| | Drake's Island Battery .. .. .. | 5 | .. | 21 | .. |
| | Fort Stamford .. .. .. .. .. | .. | .. | 7 | .. |
| Pembroke .. | Stack Rock Fort .. .. .. .. .. | 6 | 16 | .. | 7 |
| | South Hook Fort .. .. .. .. .. | .. | .. | 5 | 15 |
| | Hubberstone Battery .. .. .. .. | .. | 1 | 11 | 15 |
| | Popton Battery .. .. .. .. .. | .. | 1 | 13 | 14 |
| | Chapel Bay Battery .. .. .. .. | .. | .. | 6 | .. |
| | St. Catherine's Fort .. .. .. .. | .. | .. | 3 | 8 |
| | Proud Giltar Battery .. .. .. .. | .. | .. | .. | 2 |
| | East Moor Battery .. .. .. .. | .. | .. | .. | 4 |
| | Trement Battery .. .. .. .. .. | .. | .. | .. | 5 |
| | Freshwater West Battery .. .. .. | .. | .. | .. | 4 |
| Portland .. | E. Verne Battery .. .. .. .. | .. | .. | 27 | .. |
| | Portland Breakwater Fort .. .. | .. | 14 | 15 | .. |
| | Nothe Fort .. .. .. .. .. .. | .. | 6 | 4 | .. |
| Thames .. .. | Coalhouse Fort .. .. .. .. .. | .. | 28 | .. | .. |
| | Cliffe Fort .. .. .. .. .. .. | .. | 20 | .. | .. |
| | Shornemeade .. .. .. .. .. .. | .. | 20 | .. | .. |
| | Slough Fort .. .. .. .. .. .. | .. | .. | .. | 7 |

* Puckpool besides mounts thirty 13" howitzers. † Six guns in turrets.

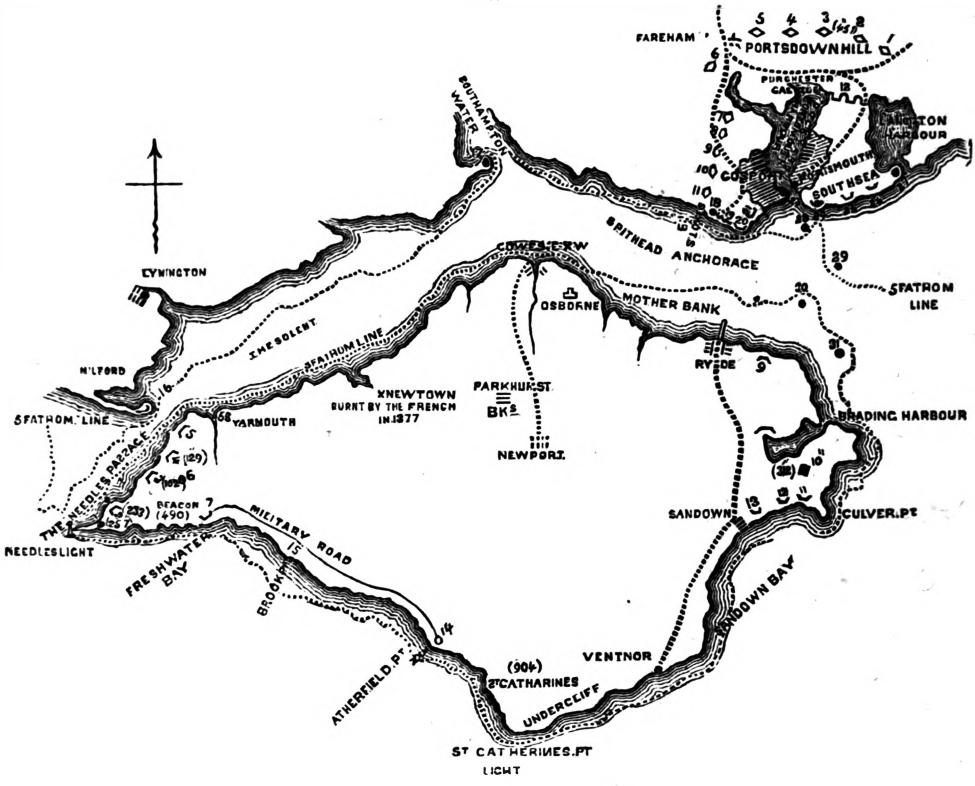
TABLE C—*continued.*

| Name of Work. | | Description of Gun. | | | |
|---|---|---|---|---|---|
| | | 12" Gun, 25 Tons. | 10" of 18 Tons. | 9" of 12 Tons. | 7" of 6½ Tons. |
| Medway .. .. | Grain Fort .. .. .. .. .. .. | .. | 11 | 4 | .. |
| | Grain Battery .. .. .. .. .. | .. | .. | 10 | .. |
| | Garrison Point Battery .. .. .. | .. | .. | 36 | .. |
| | Hoo Fort .. .. .. .. .. .. | .. | .. | 11 | .. |
| | Darnet Fort .. .. .. .. .. .. | .. | .. | 11 | .. |
| | *Queensborough .. .. .. .. .. | .. | .. | 2 | .. |
| | Cheney Rock .. .. .. .. .. | .. | .. | 2 | .. |
| Cork .. .. | Spike Island .. .. .. .. .. .. | .. | 4 | 12 | .. |
| | Carlisle .. .. .. .. .. .. .. | .. | 4 | 3 | 12 |
| | Camden Fort .. .. .. .. .. .. | .. | .. | 8 | 6 |
| | General Total .. .. | 896 | | | |

* Two guns in turrets.

Fig. 2016 shows a general plan of the defences—coast and inland—of Portsmouth, Spithead, and Isle of Wight.

2016.




REFERENCES.

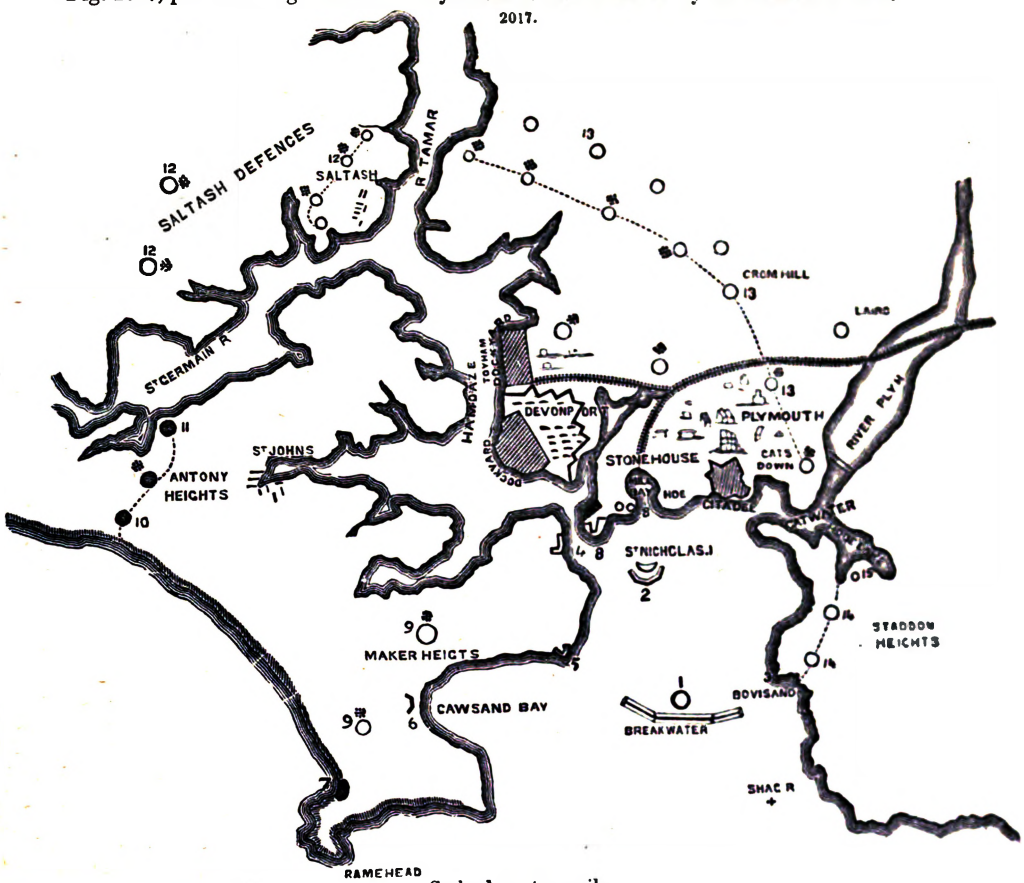
*Land Defences.*

1. Fort Purbrook.
2. ,, Widley.
3. ,, Southwick.
4. ,, Nelson.
5. ,, Wallington.
6. ,, Fareham.
7. ,, Elson.
8. ,, Brockhurst.
9. ,, Rowner.
10. ,, Grange.
11. Fort Gomer.
12. Hilsea Lines.

*Coast Defences.*

1. Needles Battery.
2. Hatherwood Battery.
3. Warden Point.
4. Cliff End.
5. Fort Victoria.
6. Goldenhill.
7. Freshwater Battery.
8. Yarmouth Battery.
9. Puckpool Battery.
10. Bembridge Fort.
11. Yaverland Battery.
12. Redcliff Battery.
13. Sandown Fort.
14. Atherfield Battery.
15. Brook Battery.
16. Hurst Castle.
17. Calshot Castle.
18. Browndown Battery.
19. Stoke Bay Lines.
20. Gillkicker Battery.
21. Fort Monckton.
22. Blockhouse Point.
23. Point Battery.
24. Southsea Castle.
25. Lump Fort.
26. Eastney Fort.
27. Fort Cumberland.
28. Spit Fort.
29. Horse Sand.
30. No Man's Fort.
31. St. Helen's Fort.

Fig. 2017, plan showing defences of Plymouth as recommended by commission of 1860.

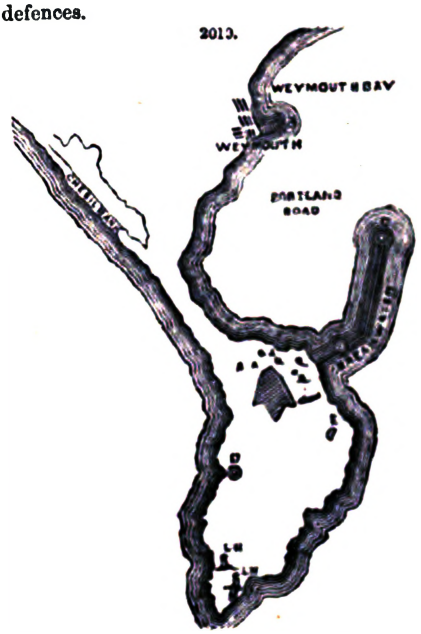



Scale, ½ in. to a mile.

REFERENCES.

1. Breakwater Fort.
2. St. Nicholas Island Fort.
3. Bovisand Battery.
4. Mount Edgcumbe Battery.
5. Picklecombe Battery.
6. Cawsand Battery.
7. Polhawn Battery.
8. E. King and W. King.
9. Knatterbury Hill and Maker Heights.
10. Tregantle Fort.
11. Scraesdon.
12. Saltash defences.
13. N.E. defences.
14. Staddon works.
15. Hooe Lake Fort.

Fig. 2019, plan of Portland Harbour and its defences.

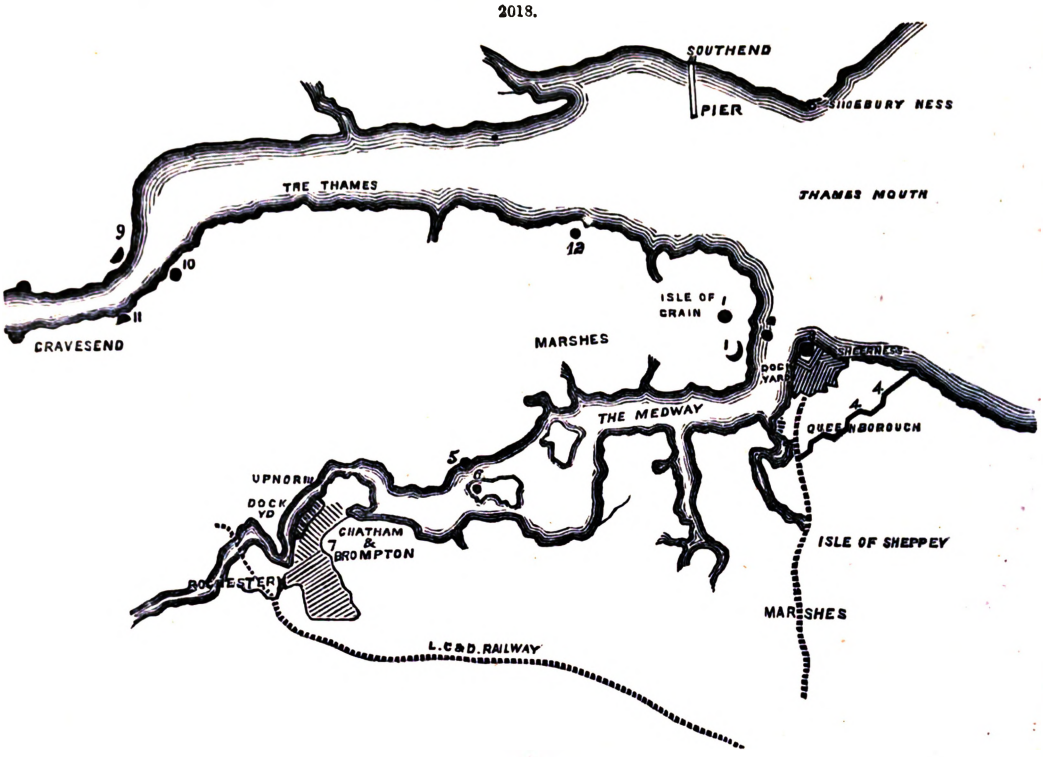



Scale, ½ in. to a mile.

*References*:—A, Verne Battery. B, Nothe Fort. C, Breakwater Fort. D, Blacknor Fort.

Fig. 2018 shows the defences at the entrance of the Thames and Medway. The channels will be further protected by obstructions, floating and hidden.

2018.




REFERENCES.

| | | | |
|---|---|---|---|
| 1. Isle of Grain Fort and Battery. | 4. Sheerness Lines. | 7. Chatham Lines. | 10. Cliffe Creek. |
| 2. Grain Tower. | 5. Hoo Fort. | 8. Tilbury Fort. | 11. Shornemeade Battery. |
| 3. Garrison Point. | 6. Darnet. | 9. Coalhouse Point. | 12. Slough Battery. |

See ARMOUR. ARTILLERY. BATTERY. FORTIFICATION. GUNPOWDER. MATERIALS OF CONSTRUCTION. ORDNANCE.

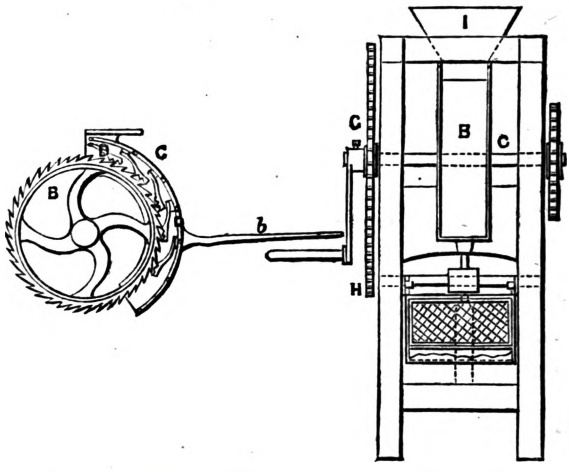
*Works on Coast Defences*:—Baron P. E. Maurice, 'On National Defence in England,' 8vo, 1852. Sir R. Gardiner, 'Considerations on National Defence,' 8vo, 1860. 'Reports of the Defence Commission of 1860,' and that of 1869. General Barnard, 'Notes on Sea-coast Defence,' 8vo, New York, 1861. G. P. Bidder, jun., "National Defences," 'Minutes Inst. C. E.,' 1861. Laisné, 'Aide Mémoire,' edit. 1864. 'Report of the Secretary of the Navy on Coast and Harbour Defences,' Washington, 1865. Von Scheliha, 'Coast Defence,' 1867. Commander J. S. Barnes, 'On Submarine Warfare,' 8vo, New York, 1869. Von Wurmbs, 'Lehrbuch der Kriegs Baukunst.' Brialmont, 'Défenses des Etats.' Straith's 'Fortification.' Sir J. Burgoyne, 'Papers on Military Subjects.' 'Aide Mémoire' of Royal Engineers, and Professional Papers of same corps, New and Old Series. 'Reports of Artillery Experiments at Shoeburyness.' Articles on "Our Fortifications" in 'The Times.' Captain Piron, 'Essai sur la Défense des Eaux.' 'Les Ports Militaires de la France,' par MM. Eymen, De Boro, Hébert, Bouchet et Calvet, 8vo, Paris.

COFFEE MILL. FR., *Moulin à café*, GER., *Kaffeemühle*; ITAL., *Macinello*, SPAN., *Molino de café*.

See MILLS.

COFFEE-HULLING MACHINE. FR., *Machine à égrèner les grains de café*; GER., *Maschine zum schälen der Kaffeebohnen*; ITAL., *Macchina da sgusciare il caffè*; SPAN., *Maquina para descascarar café*.

2020. 2021.




Sections of A. Angell's Coffee-hulling Machine are shown, Figs. 2020, 2021. The coffee is fed

in through a hopper I, and passes between the roughened surfaces of a hulling cylinder B, and the serrated spring strippers D. During this operation the hull or husk is effectually separated from the kernel.

Referring to Fig. 2021, it will be seen that the strippers D are arranged side by side, one in advance of the other, in a series, within a hollow lid C, to which they are secured. The lever *b* serves to regulate the pressure on hulling cylinder B, and the machine is operated by the cog-wheel G gearing into a pinion H. See GIN.

COFFER-DAM. FR., *Bâtardeau;* GER., *Fangdamm;* ITAL., *Diga; Tura;* SPAN., *Ataguia.* See DAMS.

COG-WHEELS. FR., *Roues dentées;* GER., *Zahnräder;* ITAL., *Route dentate;* SPAN., *Rueda dentada.* See GEARING.

COHESION. FR., *Cohésion;* GER., *Cohäsion;* ITAL., *Coesione;* SPAN., *Cohesion.* See MATERIALS OF CONSTRUCTION, *Strength of.*

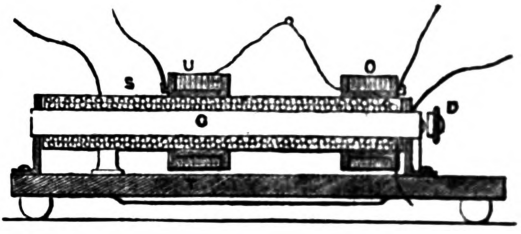
COIL. FR., *Glène;* GER., *Aufgeschossenes Tau;* ITAL., *Rocchetto d'induzione;* SPAN., *Bobina.*

*Electro-magnetic Induction.*—An *induction coil* has an influence by which an electric or galvanic current produces magnetic polarity in certain bodies near or round which it passes.

*Magneto-electric Induction* is the influence by which a magnet excites electric currents in closed circuits.

The *Induction Coil* of J. Kidder, Fig. 2022, consists in arranging the fine insulated wire which composes the helix or helices, U, O, used upon a magnet S, G, for obtaining an induced current or currents, either wholly or in greater quantity at or near the centre of the length of the magnet, or what is termed its neutral portion, in combination with the arrangement of the inner or primary coil S, and its core of soft iron G. The said helix or helices are made adjustable upon the magnet between the poles of S, D, and the so-called neutral portion thereof, for the purpose of varying the power of the induced current. S, G, D, is securely fixed to the base T. See BORING AND BLASTING, p. 573. TELEGRAPHY.

2022.




COKING OVEN. FR., *Four à coke;* GER., *Coaksofen;* ITAL., *Fornace da arso;* SPAN., *Horno para hacer coke.* See OVENS.

COLLAR. FR., *Crapaudine;* GER., *Spur-ring oder Spurscheibe;* ITAL., *Collare;* SPAN., *Anillo.*

A collar is a ring-like part of a machine, used commonly for restraining irregularity of motion or for holding something to its place; as the *collar* of a pump or steam-cylinder, which is a plate of metal screwed down upon the stuffing-box, with an aperture through which the piston-rod passes; the *collar* of a shaft used to prevent the shaft from shifting its place endwise, and the like.

A *collar-beam*, or collar, is a horizontal piece of timber connecting and bracing two opposite rafters.

COMBING MACHINE. FR., *Peigneuse;* GER., *Kamm Maschine;* ITAL., *Macchina da pettinare.* See FLAX MACHINERY. WOOL-WORKING MACHINERY.

COMPASS. FR., *Boussole;* GER., *Compass;* ITAL., *Bussola;* SPAN., *Brújula.*

A compass is an instrument consisting essentially of a magnetized needle turning freely on a point, used to determine horizontal directions, in reference to the north and other cardinal points.

An *Azimuth compass* is one constructed like the *Mariner's*, except that the card is accurately divided into 360°, and the instrument is furnished with two sights, and has a motion in azimuth. It is chiefly used to note the actual magnetic azimuth, from which is determined the variation or declination of the magnetic needle.

The Mariner's compass is one which has its needle permanently attached to a card so that both move together. The card is divided into thirty-two parts or points, called also rhumbs, and the glass-covered box containing it is suspended in gimbals, in order to preserve its horizontal position.

A *Surveyor's compass* is one having the needle suspended by itself, and with a graduated circle of 360°, on which the needle indicates the angle between a given direction and the magnetic north. It is also furnished with two sights.

*Variation compass*, one of delicate construction employed in observations on the variations of the needle. See COMPASSES.

COMPASSES. FR., *Compas;* GER., *Zirkel;* ITAL., *Compassi;* SPAN., *Compas.*

A *compasses* is a simple instrument for describing circles, measuring figures, and so on. It consists of two, or rarely more, pointed branches or legs, usually joined at the top by a rivet, on which they move.

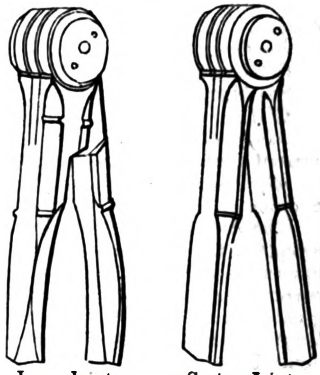
Compasses used for drawing purposes admit of many refinements, and vary in construction in many ways. With draughtsmen the first consideration is a perfect joint, of the making of which there are two distinct methods, one adopted pretty generally on the Continent and sometimes in England, called the *long joint*, and the other the *sector joint*. In the long joints, the head extends some distance down the body, as shown in Fig. 2023; consequently, with the closing of the compasses, a larger amount of surface comes continually into action, producing much greater friction and stiffness when the instrument is nearly closed than when it is wide open. This is the fault of the joint; its only merit is that it requires little skill in making, as it admits of fitting up if the work has been commenced improperly. It is universally used for common instruments, for which it answers very well if properly made. The other form of joint in use, technically called the *sector joint*, Fig. 2024, is now made to all compasses with any pretence to good quality of workman-

ship. In this joint the working surfaces are of circular form, equally distributed around the centre; consequently, the compasses move with equal pressure whether nearly closed or wide open. It is not necessary to screw the centres of sector-jointed compasses tightly, as the surfaces are not required to come in perfect contact—for this reason, that after the sector joint is made, the workman lubricates between the joint with hot beeswax, which aids in producing that peculiar deadness in movement so much esteemed in the sector joint. If the joint be made true the wax will never leave it. The writer has parted sector joints which have had twenty years of constant wear; the wax appeared the same in quantity as when first introduced, although it was blackened; the amount of wear on the plates not having been sufficient to take out the fine file-marks which were left in making the joint. This is a peculiarity of the sector joint which no other joint possesses.

The sector joint, to attain perfect movement, should be tightened and loosened as little as possible, thus allowing it to form its own surface. Care should be taken that no oil gets upon the joint, as it speedily dissolves the wax and spoils the joint.

The method of trying if a joint is perfect is to open the compasses until they are in line, and then to close them again very slowly, noticing if equal pressure is required at all openings; this will test the evenness of the joint. Another important consideration is, that the centre should fit perfectly; to examine this it will be necessary to take the compasses about half open, and close and open them alternately and quickly for as small a distance as possible, as it were to feel the joint. In doing this, if the centre should not fit, a slight jerk will be felt immediately after commencing to open or close them. Improperly-made sector joints are worse to work with than improperly-made long joints.

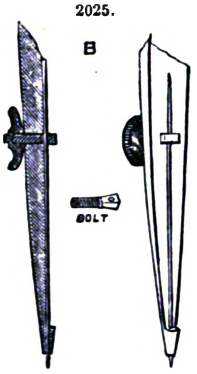
2023. 2024.



Long Joint. Sector Joint.

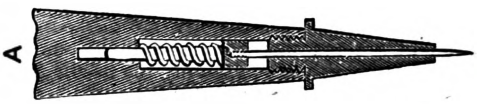
With regard to compasses with changeable points, there are two ways of fixing the points to the compasses: in one manner by an angular pin which fits into a socket and is secured by a screw, and the other very much better plan of a cylindrical socket opened on one side, so that it forms a spring. In the first plan the screw is always slipping its thread or getting lost. The opening legs of Drawing compasses are occasionally made of tubes; these are termed Tubular compasses. These have inner tubes, or, what is better, solid bars, fitted telescopically, which extend the legs to take higher radii if required. With tubular compasses, the points turn on an axis, so that there are no loose pieces; these kind of compasses are preferred by many mechanical draughtsmen. A smaller kind of compasses, termed bows, have a handle above the head joint. In the common English construction of this instrument the opening joint is placed very near to the centre of the instrument. This is obviously wrong; the opening joint should be placed as near to the top of the instrument as is consistent with allowing just sufficient length to form a handle. The hollows are better placed sloping inwards than outwards. In compasses, Figs. 2025, 2026, of a superior class, the points of which are made to carry needles, Stanley, of Great Turnstile, Holborn, has made improvements which are said to obviate the general shakiness of these points. Instead of splitting the point down in the English fashion, or boring a cylindrical hole up the point, in the Continental fashion, to contain the needle, in the new plan a conical hole is bored from the back of the point, so that when the needle is pressed into the hole it is wedged sufficiently to hold it firm. The back of the needle is secured by a cross-bolt, which holds the needle more firmly than it is held in any other plan in use. Stanley also makes another point, especially for tracings. In this point the needle is pressed forward by a soft spring, so that it merely bites the surface of the paper sufficient to make a circle without entering it in a perceptible degree. This is a very useful point for tracing from old drawings with large centre-holes, or in a general way for a draughtsman with a heavy hand.

2025.



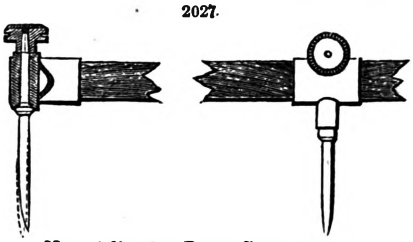

Section. Front of Point.

2026.




Enlarged Section of Stanley's Spring Point.

2027.



New Adjusting Beam Compasses.

*Beam Compasses*, Fig. 2027.—These are distinct from those described above, in having no joint; the distance between the points being obtained by a pair of heads sliding on a lath or beam. The points are made plain, or for ink and pencil, as in the ordinary drawing compasses. The general method of fine adjustment is by a screw at the end of the beam which is made to carry one of

the heads with its motion. A. Strange has introduced a new adjustment in these beam compasses, now being used in plotting the survey of India. This is shown in Fig. 2027. It consists of a point with a socket joint fitted into the end of the beam compasses. The point, after being properly ground to its socket and fitted with a milled head above, is bent below the socket, so that the point is made an eccentric. In taking a distance off with this beam, after clamping the movable head as nearly as possible to the distance required, the milled head is slightly turned either way, and the point brought exactly to the position with great precision and ease.

*Reconnoitring Compass, for the use of military men, travellers, geologists, and so on.*—Every traveller, when exploring a new country, should be provided with a portable compass, to find his way when the sun or the stars are not visible. Such an instrument, to be complete, should be capable of being used in the hand, as well as of being placed on a stand, for the purpose of observing horizontal angles. We ought also to be able to place it upon a board M, Figs. 2028, 2029, for the purpose of setting it, by means of notches *d* in the centres of the squares of the plane.

The compass which we give appears to satisfy all these conditions. As usual for this kind of instrument, it is in the form of a watch; it has a small pendulum P for observing vertical angles. The following are the additions which have been made to it:—

1. A small flat piece *b b* has been fixed to one side; the use of this part is to observe horizontal or vertical angles. For these latter angles it offers special advantages when the observer wishes to take inclines which do not reach the eye, as in the case of the profile of a distant mountain.

2. The bottom of the compass has been provided with a female screw C, Fig. 2028, for the purpose of fixing it to a table by means of the screw *d*, or to a stand by means of the movable rest T', Fig. 2030, similar to the one described for Burel's level. They are affixed to the compass in the same way as a key to a watch.

3. A small reflector A, quicksilvered half upon one face, half upon the other, and turning upon a hinge F, Figs. 2028, 2029, is fixed to the ring of the compass. This reflector serves as a limb when the instrument is placed upon a stand, or even when held in the hand. When on a stand, dipping or descending angles are observed on the upper side of the reflector, and ascending angles on the lower side.

When held in the hand, the eye, being situated above the limb to observe descending angles, may at the same time read the degree marked by the needle; but in the case of ascending angles, the eye, being situated below the compass to see the opposite side of the reflector A, cannot see the degrees. To remedy this, Captain Hossard quicksilvered a portion A' of the glass of the compass. By this means we may see the image of the eye in the reflector A', and make it coincide, in the same vertical plane, with the image of the object observed reflected by the reflector A. When the planes perpendicular to A and A' coincide, they form a plane perpendicular to the hinge F, and consequently a new reflecting limb, which is such that, the point observed being situated above the eye, the eye may at the same time be situated above the compass, and thus read the degrees marked by the needle. A small flat piece of mica *g*, adapted to the extremity of the compass-needle, enables the observer, by inclining it a little, to apply friction to the limb, and so arrest its oscillations.

The reflector A, being quicksilvered on both sides like those of Burel's level, the compass may, in a case of need, be transformed into a level. For this purpose it is sufficient to apply a screw to the reflector to regulate its verticality when the instrument is suspended by the cord H H, Figs. 2028, 2029. This cord, passing through in H to the opposite side of the compass, allows it to be suspended for the purpose of taking directions in mines. This compass costs 55 francs.

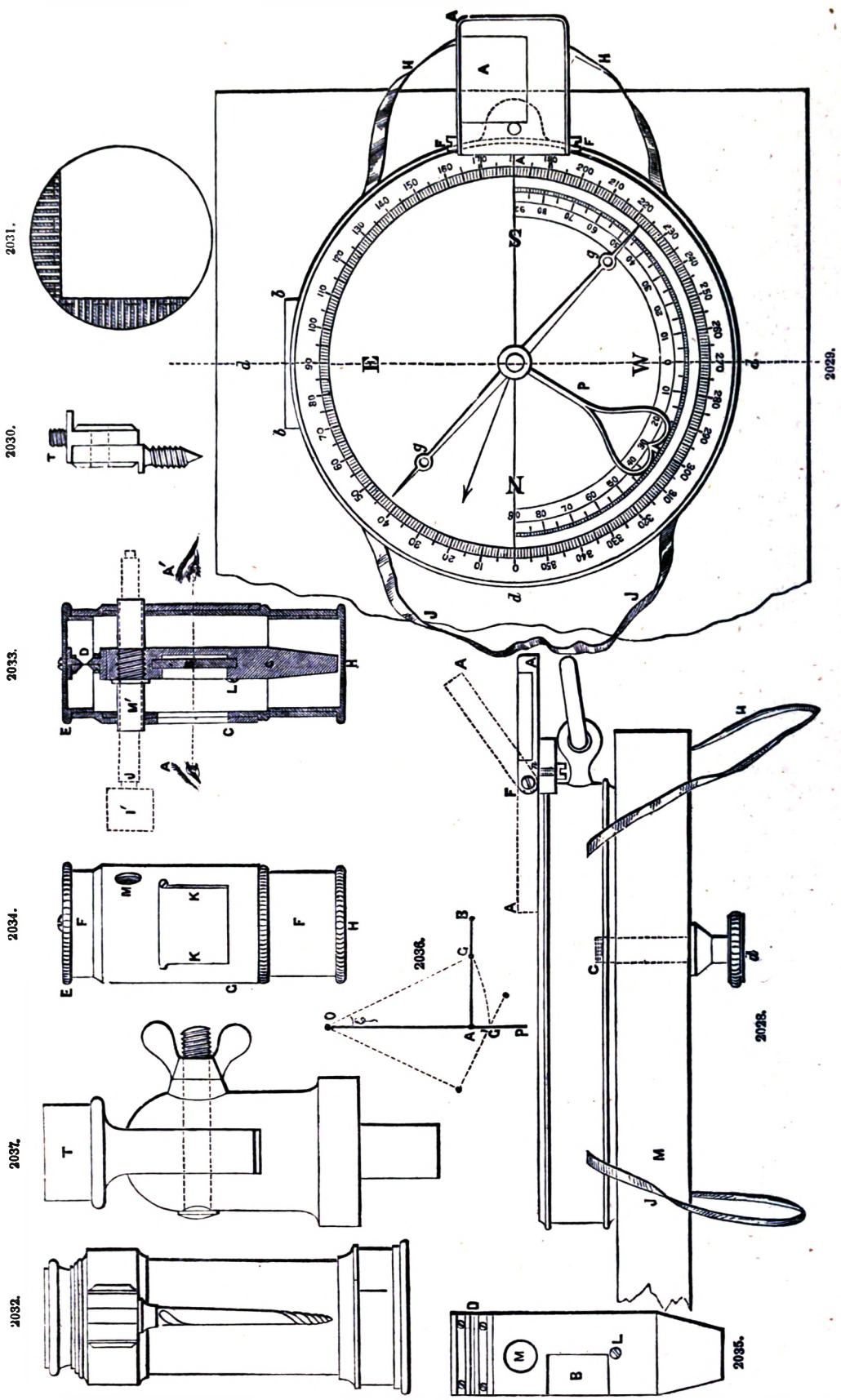
*Field-glass with Support and a Micrometer for determining distances.*—Having procured a level and a compass, a third instrument not less useful is requisite: this is the field-glass, not merely for distinguishing distant objects, but for determining distances by the addition of a micrometer at its focus. Those are most portable and clear which reverse the objects: this is a small inconvenience for those who are accustomed to such glasses. A small micrometer, engraved upon gelatine, in which the millimètre is divided into 8 or 10, is sufficient to determine distances with tolerable accuracy by means of the formula $X = \frac{H}{h}\phi \times 100$, in which X is the distance from the object to the object-glass; H the size of the object; $h$ the number of divisions which it intercepts upon the micrometer; $\phi$ a constant coefficient, determined by experiment when X, H, and $h$ are known. It is the focal distance of the object-glass, measured in parts of the micrometer. The formula $X = \frac{H}{h}\phi \times 100$ is engraved upon the cover of the field-glass with the value of $\phi$, which varies from 11 to 12.

We find also upon the cover another formula $X = \frac{a c \cdot h'}{h' - h}$ relative to the case in which, H being unknown, two successive observations, $h$ and $h'$, are made at a distance $a c$ from the object. The divisions of the micrometer are marked in fives by a small bar, for ease in reading: Fig. 2031 represents the appearance of this micrometer. There is a horizontal and a vertical one, enabling the observer to draw upon paper divided into squares the portion of the landscape comprised in the field of vision.

In order to make a careful observation with the field-glass, we must be able to fix it. This is easily effected by means of a gimlet fixed to the rim by a hinge movement like that of compass-heads, Fig. 2032.

*Burel's Reflecting Level.*—The advantages possessed by this instrument are:—

1. The simplicity of its construction and rectification.
2. The length of its line of sight.
3. The readiness with which it may be used, even in the hand without a stand to rest it upon.
4. The smallness of its size.


2029.
2028.
2030.
2031.
2032.
2033.
2034.
2035.
2036.
2037.

*Description of the Instrument.*—The principle upon which this level is constructed is this, namely, that the line A A, Fig. 2033, which joins the centre of the eye and the centre of its reflection, is horizontal when the reflector is vertical.

The instrument consists of a reflector B fixed in a small pendulum C, which naturally retains the vertical position by turning about the horizontal axis D, by means of a single piece of ribbon. A lid E, Fig. 2034, fitted to the tube F, shuts in the instrument and protects it from the wind. An aperture K K in the tube F allows the reflector to be seen; this aperture is closed by turning a second tube G. A stopper H closes the tube F at the bottom.

To use the instrument, withdraw the stopper H, open the aperture K K, and looking into the reflector, bring the image of the eye-ball upon its edge, so as to make it coincide with the object towards which the operator is looking.

When great accuracy is required the instrument must be placed on a stand. The results thus obtained have been equal in point of accuracy to those given by the spirit-level. [A result established from experiments made at Lyons by order of Lieutenant-General Rohault de Fleury, who was the first to conceive the idea of applying the principle of reflection to levels.]

When an approximative value is sufficient, the tube may be held in the hand.

These levels were first constructed with a double suspension; it has since been discovered that one is sufficient. They also bore in the middle of the reflector a horizontal line; this line was found to be embarrassing, especially when the instrument was used in the hand; it necessitated the holding of the image of the eye upon it, which was always a difficult operation; many forgot it, looked only upon this horizontal, and thus obtained an inclined line of sight.

*Rectification of the Instrument.*—The reflector B, Figs. 2033, 2035, is quicksilvered, half upon one side, half upon the other. It follows from this arrangement that the instrument is reversible, and that, if it is properly set, we ought to obtain the same result by using either face of the reflector. This arrangement renders the rectification of the instrument very easy, and enables us at any moment to verify its adjustment. When its adjustment is not correct, it may be rectified by means of the screw L which presses upon the reflector and changes its inclination.

This mode of rectification supposes the two faces of the reflector parallel.

*Measuring and Tracing Inclines.*—To render the instrument capable of measuring or tracing inclines, a rod J furnished with a heavy head I is introduced into the hole M in the pendulum C, Fig. 2033. The reflector thus assumes an inclined position, and the trigonometrical tangent of the angle of inclination sought, is proportional to the distance from the centre of gravity of the weighted rod to the reflector.

The division of the tube J is founded upon the following demonstration, due to Goulier.

A heavy rod O P, Fig. 2036, is suspended at the point O. Its centre of gravity is at A. Under the action of weight, this rod is vertically in equilibrium.

Suppose at the point A, at right angles with O P, another rod A B fixed to it in any manner; suppose the centre of gravity of this second rod at the point B, what will be the position of equilibrium of the system?

Let $p\,p'$ be the weights of the two rods applied at the points A and B; their resultant $p + p'$ passes to the point G of the line A B determined by the relation $\frac{G\,B}{A\,G} = \frac{p}{p'}$.

The system, under the action of the force $p + p'$, will turn about the point O, until G has arrived at G′ upon the vertical passing through the point O.

Let us now determine the angle $\phi$.

We deduce from the relation $\frac{G\,B + A\,G'}{A\,G} = \frac{p + p'}{p'}$, or $\frac{A\,B}{A\,G} = \frac{p + p'}{p'}$.

Now A G is the trigonometrical tangent of the angle $\phi$, therefore $A\,G = R \tan. \phi$, whence $\tan. \phi = \frac{A\,B}{R} \times \frac{p'}{p + p'}$.

But $\frac{p'}{R\,(p + p')}$ is a constant quantity K, therefore $\tan \phi = A\,B \times K$; tan. $\phi$ is, therefore, proportional to A B.

If the rod A B be divided into equal parts, we shall have the measure of tan. $\phi$.

To effect the division of the rod, the tangent of the angle $\phi$ must be determined directly, and this value introduced into the equation; from this we may deduce the number of divisions corresponding to this particular value of the angle. We shall then have merely to continue the division upon the rod.

If now we wish to take the angle of a plane with the horizon, the rod must be thrust in to a greater or less degree; this will cause the mirror to incline, and when the eye sees its image coincide with the object looked at upon the line of inclination, the reflector is perpendicular to the incline. The angle of the reflector with the vertical (the angle $\phi$) equals, therefore, and serves to measure the angle of the inclined plane with the horizon.

As the reflecting pendulum is inclined during the observation, the tube F should also be held inclined. If the tube be mounted on a stand, the stand should be provided with a movable rest T, of wood, Fig. 2037, fitted to the tube F; or of copper, T′, Fig. 2030, fitted to the stopper H.

When we have to measure an incline the tangent of which exceeds the length of the rod J, the solid cylinder I must be drawn out, and the second numbering of the tube J used. The division upon the end of the tube M′ may be adapted at pleasure to the pendulum. Care must be taken to screw it on the side of the screw L, and to introduce the tube J into the tube M′ on the same side. Ascending inclines are always observed on the face of the reflector corresponding to the screw L, and descending slopes on the opposite face. If, therefore, after having observed an ascending incline, it be required to observe a descending one, M′ must be unscrewed, the opposite face of the reflector brought forward, and M′ re-screwed on the side of the screw L.

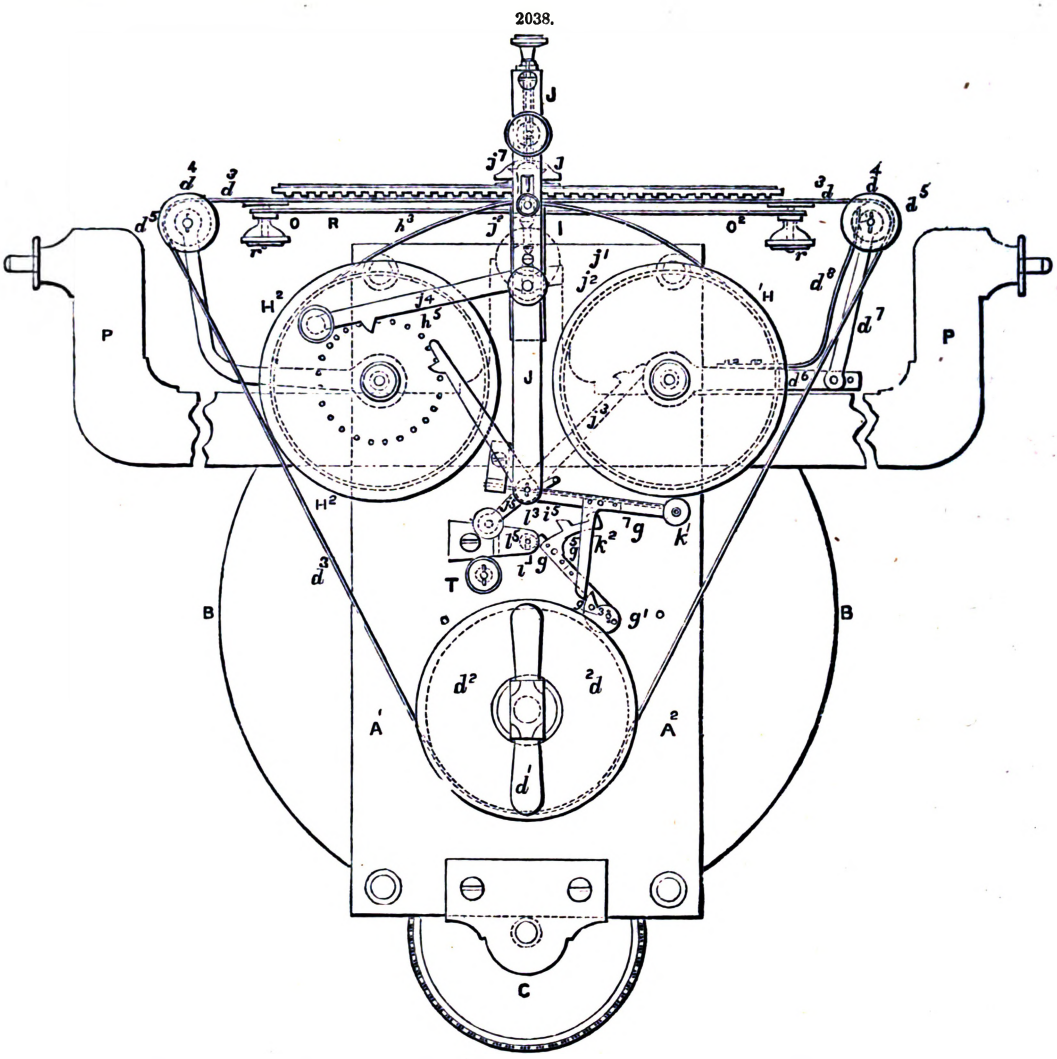
It is obvious that the axis D must be horizontal to enable the ribbon to which the reflector is suspended, and, consequently, the whole system, to turn freely under the action of the rod. It has been found, however, that on holding the instrument in the hand, its weight is sufficient to move the apparatus in a vertical plane. Thus we have the required condition of exactness.

*Level reduced to the Reflecting Pendulum and its Axis*, Fig. 2035.—The instrument has been reduced to its simplest expression by retaining only the pendulum C, with its reflector B, and its axis. In this condition it is still very convenient to use in the hand, even in taking inclines; but it is more exposed to the wind, and it can be placed upon a stand only by means of a screw-ring fixed on one side of the stand and passing, on the other, through a little cylinder placed for this purpose on the upper portion of the level. This little cylinder is not represented in the Fig. 2035.

*Level serving as a Goniometer.*—The base of the tube F, Figs. 2033, 2034, may be easily divided at every five degrees, and a corresponding portion of the rest T, Fig. 2037, inlaid with copper, serves as a vernier.

Figs. 2038 to 2040 represent front, back, and side elevations respectively of a mariner's or ship's compass invented by A. Albini; Fig. 2041 is a plan of the same; Fig. 2042 is a plan of the under-side of the compass card, and Figs. 2043, 2044, are sections of the said card; Figs. 2045 to 2047 are front elevations of the mechanism by which the sliding bar hereafter referred to is raised and lowered; Figs. 2048, 2049, are a side elevation and a plan respectively of the said mechanism; Figs. 2500, 2051, are detached parts of the same. The same letters of reference indicate the same parts in each figure.

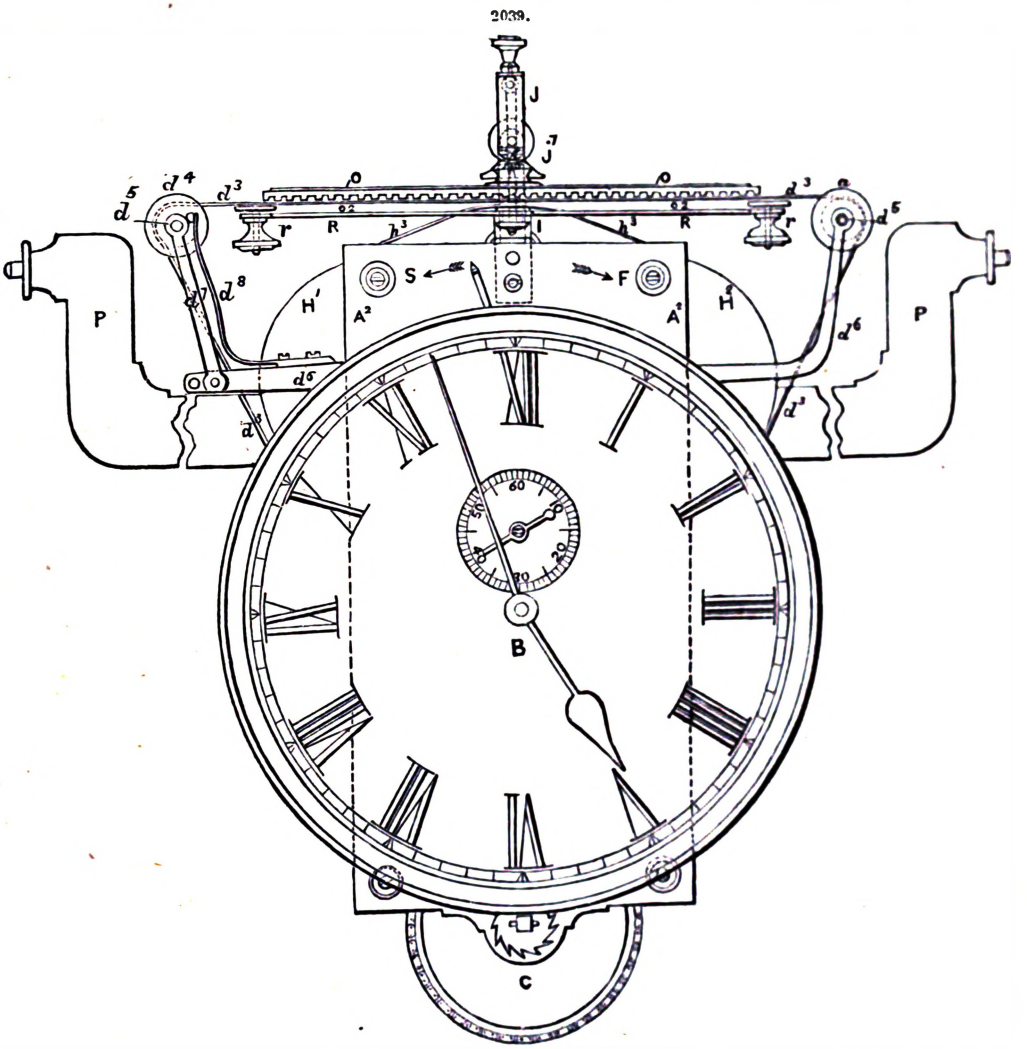
2038.




$A^1$, $A^2$, are the front and back plates carrying the several parts of the compass; O is the compass card, the position of which is seen in the several figures. The said card O is furnished with a magnetized bar $o^1$ carrying sliding weights $o^3$, $o^3$, by means of which the balance of the card can be adjusted as required. $o^2$ is a metallic ring affixed to the under-side of the compass card O, the ring being furnished with raised letters or printing types indicating the points of the compass, the letters or types of the ring $o^2$ being situated under and corresponding to those on the compass card O. The said compass card fitted with its printing ring is suspended by and

turns on a central pointed support in the usual manner, as represented in the figures. The construction of the compass card and its metallic printing ring will be readily understood by an examination of Figs. 2042 to 2044, Fig. 2042 representing a plan of the under-side of the compass card and ring, and Figs. 2043, 2044, cross-sections of the same taken at right angles to one another. Underneath the printing ring $o^2$ of the compass card O is a bar R provided with set screws $r$, $r$, which screws $r$, $r$, by being adjusted as required under the ring $o^2$, prevent the excessive vibration of the said ring and card. $d^2$ is a drum on the axis of the fusee hereafter described. Over this drum and the pulleys $d^4$, $d^4$, an inking ribbon $d^3$ passes, which ribbon is kept in a state of tension by the said pulleys $d^4$, $d^4$. One of the axes $d^5$, $d^5$, upon which the pulleys $d$, $d$, are mounted is fixed to one of the bars $d^6$, and the other of the said axes is fixed in an arm $d^7$ which is jointed to the other bar, the said arm $d^7$ being pressed outwards by a spring $d^8$, Figs. 2038, 2039. The required tension in the inking ribbon $d^3$ is thus maintained. The

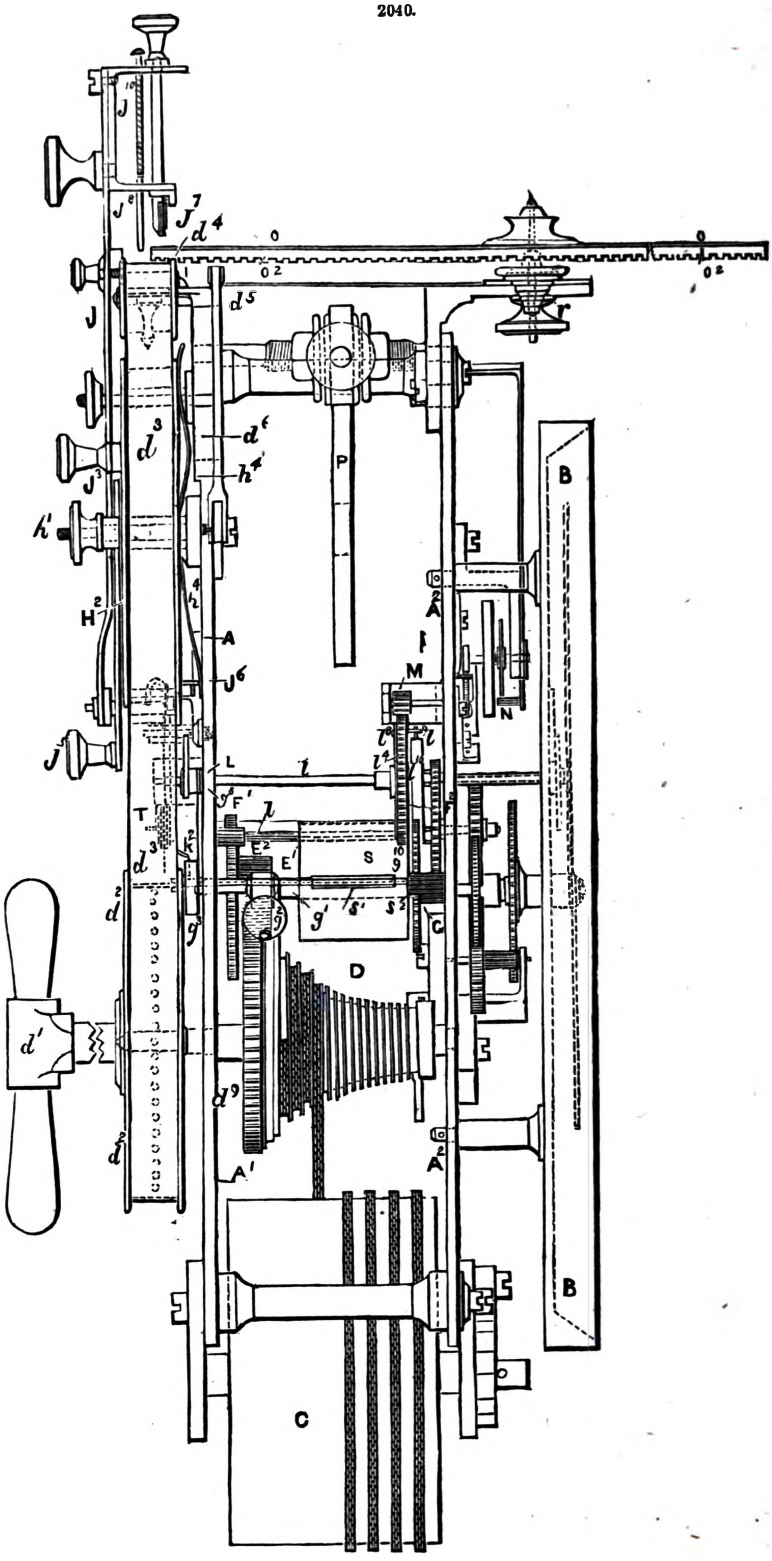
2039.




drum $d^2$ is hollow, and constitutes a reservoir for the ink, which ink passes through perforations in the periphery of the drum to a strip of cloth with which it is covered. The inking ribbon $d^3$ is by this means kept properly charged with ink. $H^1$, $H^2$, are drums situated within the inking ribbon $d^3$, Fig. 2038, around which drums a slip of paper $h^3$ is coiled. These drums turn on the axes $h^1$, $h^2$, and are steadied by springs $h^4$, $h^4$. I, is a horizontal cushion situated a little below the printing ring $o^2$ of the compass card O. On this cushion the strip of paper $h^3$ is printed. By an examination of Figs. 2038, 2039, the manner in which the strip of paper $h^3$ passes over the cushion I and between it and the inking ribbon $d^3$ will be readily seen. J is a sliding bar having guide-slots $j^1$, $j^1$, working on fixed guide-pins $j^2$, $j^2$, Fig. 2039. The bar J has a rising and falling motion communicated to it by means of mechanism actuated by the clock-work combined with the compass. To the top of the sliding bar J a small presser bar $j^7$ is affixed. The said presser bar $j^7$ is situated over the edge of the type or printing ring $o^2$ of the compass card, and at each descent of the said bar J presses down the said ring $o^2$ upon the inking ribbon $d^3$ and prints upon the strip of paper $h^3$ the course followed by the ship. Parallel

with the presser bar $j^7$ is a rod $j^8$, which on each descent of the bar J presses upon the inking ribbon $d^3$, and thereby leaves on the paper $h^3$ a dot indicating the exact direction of the ship's head, the pressure exerted by the said rod $j^8$ being moderated by a coiled spring $j^{10}$. The rising and falling motion of the sliding bar J and the feeding forward of the inking ribbon $d^3$ and strip of paper $h^3$ are effected at the proper times by mechanism constructed and actuated by clockwork in the following manner:—B is a clock dial for indicating the time, the said dial being fixed to the plate $A^2$; C is the spring or going barrel of the clock; D is the fusee, which is wound up by a handle $d^1$ on its axis. On the axis of the fusee is the drum $d^2$ over which the inking ribbon $d^3$ is passed. By the motion of the said fusee the ribbon $d^3$ is moved slowly over the drum, and a fresh portion of it is successively brought over a blank portion of the strip of paper $h^3$ for the next impression of the type or printing ring and rod. Motion is communicated from the fusee D by means of toothed wheels $d^9$, $E^1$, $E^2$, $F^1$, $F^2$, and G to an axis $g^1$, on which are fixed a counter-balance $g^2$ and snail-shaped cam $g^3$. The speed of the axis $g^1$ is retarded by a fly-wheel S on a shaft $s^1$, on which is fixed a pinion $s^2$ which is driven by a toothed wheel $g^{10}$. To the axis $g^1$ a lever $g^8$, Fig. 2050, is fixed, the end $g^4$ of which lever constitutes a detent. To the free end of the said lever $g^8$ is a segmental bar $g^5$, which is furnished with detents $g^6$, $g^7$. The detents $g^4$, $g^6$, and $g^7$, operate in conjunction with the cam L, as hereafter described. The said cam L is shown separately in Fig. 2051. Above the lever $g^8$ is another lever K turning on an axis $k^1$ and pressed down by the spring represented. The said lever K is supported by an arm $k^2$ and cam $g^3$. The lower end of the arm $k^2$ of the lever K is turned at right angles, and upon this bent part the cam $g^3$ acts. The lower end of the sliding bar J, by which the descent of the printing ring $o^2$ upon the strip of paper $h^3$ is effected, is jointed to the free end of the lever K. The sliding bar J is raised,

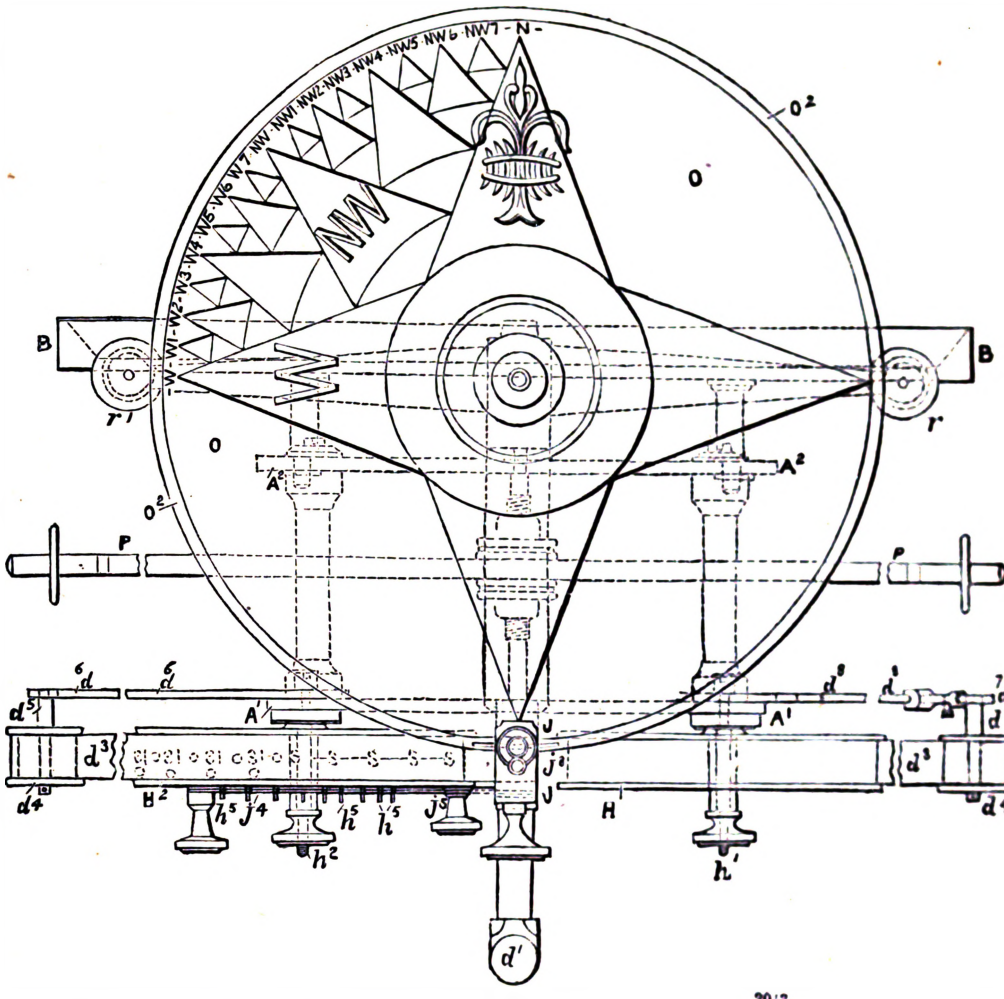
2040.




supported, and allowed to descend at the proper times by the operation of the cam $g^3$ upon the arm $k^2$ of the lever K, to which the said sliding bar J is jointed combined with the operation of the cam L upon the lever $g^8$. The cam L is double-acting, the portions marked $l^1$, $l^2$, having flat faces,

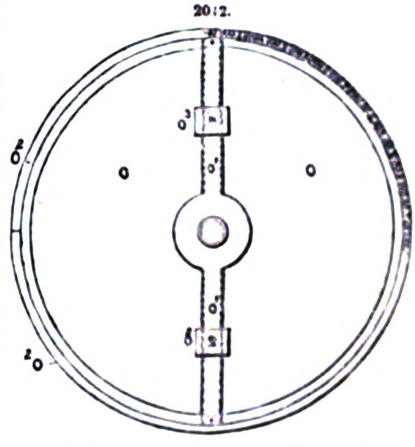
Fig. 2051. The said cam L is fixed on an axis $l^3$, which carries the seconds' hand of the clock, and gives motion by means of a toothed wheel $l^4$ to a pinion M, which is connected to a chronometer escapement N, by which the motion of the apparatus is regulated. The toothed wheel $l^4$, connected with the said escapement N, carries a movable pin $l^5$, which once a minute acts on a

2041.




pin $l^9$ on the periphery of a wind-up barrel $l^{10}$, so that in case the "going" or spring barrel C is run down, the motion of the works is stopped. The action of the parts for giving the rising and falling motion to the bar J is as follows:—When the parts are in the respective positions represented in Figs. 2038 and 2045, the sliding bar J is supported in its raised position by the arm $k^2$ resting on the cam $g^3$. At every half minute the detent $g^4$ of the lever $g^8$ escapes from the part $l^2$ of the cam L by the rotation of the axis $l^3$ of the seconds' hand, and the said lever $g^8$ falls from the position represented in Figs. 2038 and 2045 to that represented in Fig. 2046 by the partial rotation of the axis $g^1$, upon which the said lever $g^8$ is fixed, the cam $g^3$ partaking of the same motion. On the completion of the minute the detent $g^6$ of the lever $g^8$ escapes by the further rotation of the cam L from the part $l^1$, and the cam $g^3$ releases the arm $k^2$ and allows the lever K and bar J to fall, the said parts assuming the positions represented in Figs. 2047 to 2049. By the descent of

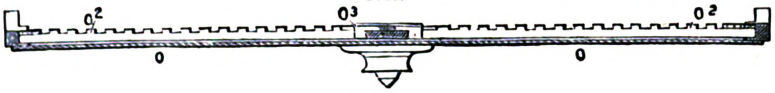
2042.



the bar J the printing of the ship's course upon the strip of paper $k^3$ is effected, the ring $o^3$ of the compass O being depressed by the presser bar $j^7$, and the rod $j^8$ at the same time being caused to make a dot on the paper. The detent $g^6$ of the lever $g^8$ having thus escaped from the cam L and caused the descent of the bar J and the printing of the ship's course, the detent $g^7$ of the said lever,

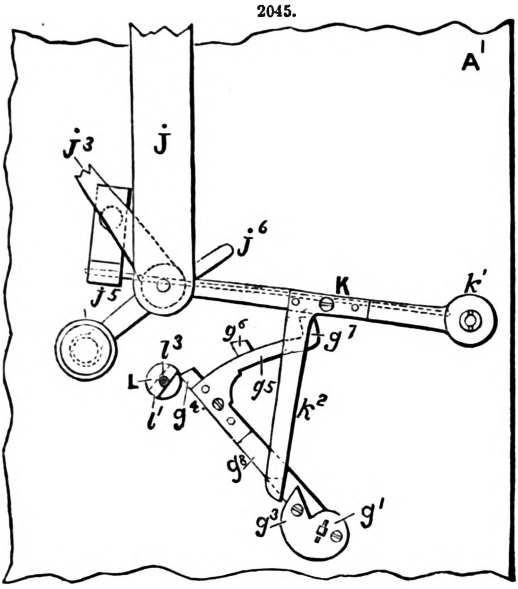
which is of slightly greater length than the detent $g^6$, rests on the said cam L for two seconds, in order to defer for that space of time the revolution of the cam $g^3$, and thus prevent the undue

2043.

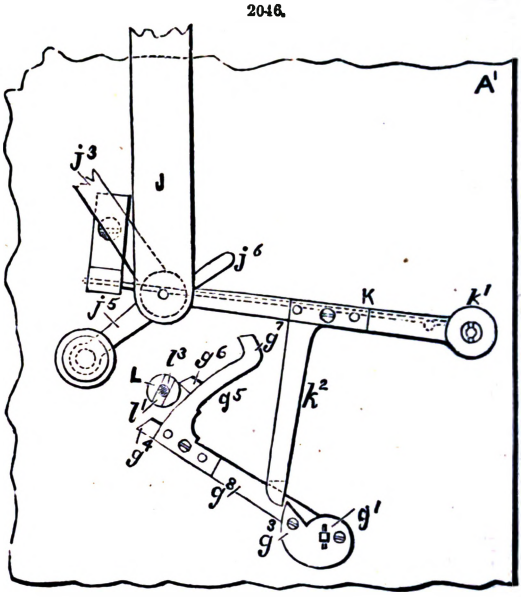



2044.

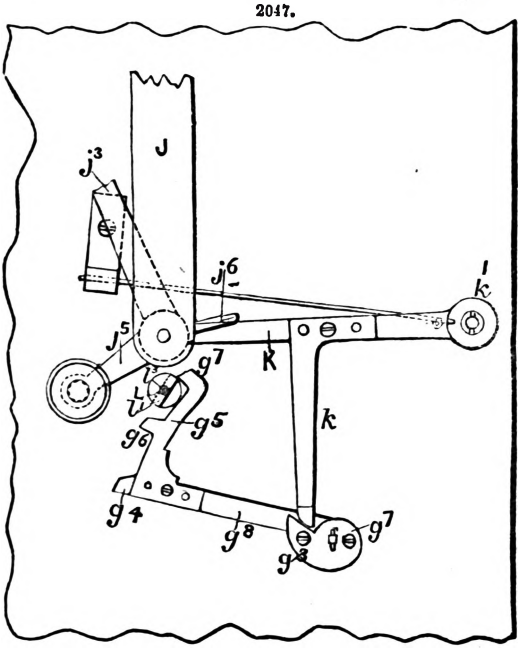
2045.



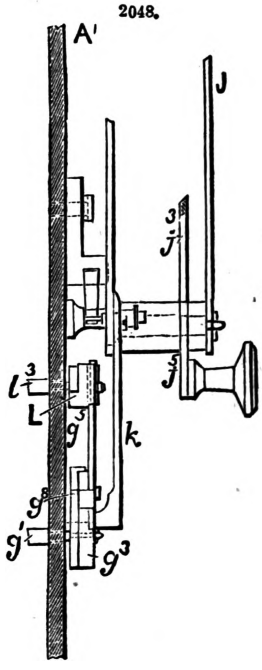

2046.




2047.



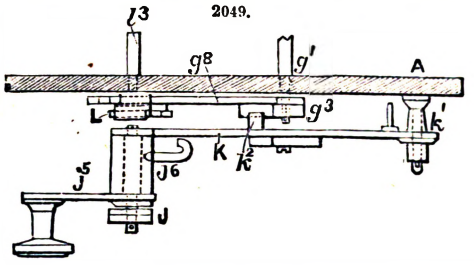

2048.



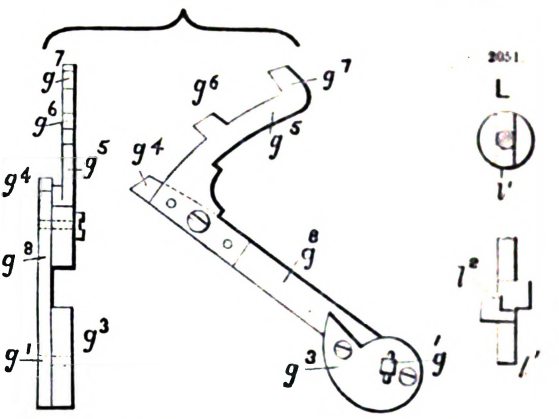

vibration of the compass card, which would result from the too sudden rise of the presser bar $j^7$ from the ring $o^2$ of the said compass card. On the expiration of the two seconds the rotation of the

cam L permits the escape of the detent $g^7$ therefrom and allows of the further rotation of the cam $g^3$, whereby the said cam is brought round to the position represented in Figs. 2038 to 2040 and 2045, and by acting on the arm $k^2$ of the lever K raises the bar J and lifts the pressure bar $j^7$ and rod $j^8$.

2049.




2050



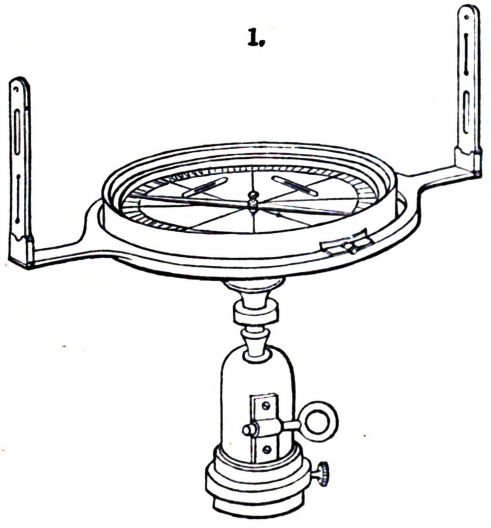

2051



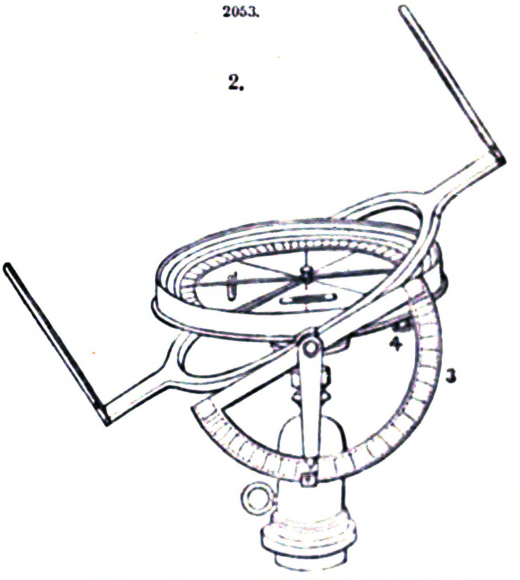

The lever $g^8$ having been brought round with the cam $g^3$ to the position Figs. 2038 and 2045, the said lever $g^8$ is again ready to be released at the proper times by the cam L and cause by its action the descent of the cam $g^3$ and the consequent fall of the bar J and the printing of the ship's course as hereinbefore described. In Fig. 2041 the printing of the ship's course and the centre of the ship's course at intervals of a minute upon the strip of paper $h^3$ is indicated in dotted lines. The strip of paper $h^3$ is shifted on the raising of the bar J so as to bring a blank part in position for the next impression in the following manner:—On the face of one of the drums $H^2$, upon which the strip of paper $h^3$ is coiled, is a series of pins $h^5$, $h^5$, one of which pins is acted upon at each ascent of the bar J by the pawl $j^3$ jointed to the lower end of the said bar J; an intermittent rotatory motion is thereby given to the drum $H^2$, the return motion of the said drum being prevented by the pawl $j^4$, which turns on one of the guide-pins $j^2$ of the bar J, Fig. 2038. Attached to the pawl $j^3$ is an elbow lever $j^5$, by means of which the said pawl $j^3$ can be thrown into or out of gear with the drum $H^2$, as may be required. The said pawl $j^3$ is furnished with a catch $j^6$ which, when the said pawl is out of gear, as indicated by dotted lines in Fig. 2038, rests on the bearing $l^3$ in which the axis $l^3$ turns and thus prevents the descent of the sliding bar J. By means of a milled button T fixed on an axis $t$ connected by toothed wheels to the motion work of the hands of the clock, the said hands may be set as required. The parts of the mechanism of the clock which I have not described are of the ordinary kind. The whole of the compass is suspended on gimbals P P', to allow for the motion of the ship. Instead of causing the descent of the sliding rod J and the printing of the ship's course at intervals of a minute, the clockwork may be so arranged as to cause the descent of the said rod J at other short intervals. In England, this compass is constructed only by Elliott Brothers, London.

*Hedley's Mining-Compass, or Dial*, Figs. 2052, 2053, invented by the late John Hedley, and manufactured extensively by John Davis of Derby. This dial possesses many advantages over the

2052.




2053.




1. The Dial as an ordinary rigid one.
2. Inclined to suit the declivity of a pit.
3. Arc attached at pleasure, for ascertaining the angle or dip
4. Screw for moving the vernier.

ordinary dial, inasmuch as it gives an operator all the advantages of the ordinary one, and in addition, by its construction, allows longer sights to be taken in pits of any declivity, by means of

a ring moving on centres. This ring, Fig. 2053, carries the sights, and can be moved to any angle, the centres remaining in all cases horizontal. To the ring is attached, when required for use, a graduated arc, which gives the vertical angle and difference for hypothenuse and base. A vernier is fixed to the horizontal circle for dialling with the fast needle. See GEODESY. HAND-TOOLS. SURVEYING.

CONCRETE. FR., *Béton*; GER., *Grundmörtel*; ITAL., *Calcestruzzo*; SPAN., *Hormigon*.

See CEMENT. CONSTRUCTION. LIME AND MORTAR.

CONDENSER. FR., *Condensateur*; GER., *Condensator*; ITAL., *Condensatore*; SPAN., *Condensador*.

See DETAILS OF ENGINES.

CONSTRUCTION. FR., *Construction*; GER., *Konstruction*; ITAL., *Costruzione*; SPAN., *Construccion*.

This article, placed under what we consider an appropriate term, is designed more for artisans engaged in ordinary building operations, than for civil and military engineers.

*Foundations.*—The foundation of a building is the horizontal platform, either natural or artificial, prepared for carrying the walls and superstructure. It must not be confounded with *footings*, which are the bases of walls made broader to distribute the weight more equally over the foundation; nor with piers, although it is not always easy to define where a foundation ends and where a pier begins: in general, all those parts of a structure which are sunk in the natural soil, the conditions of which are therefore different from those parts above ground, are foundations.

There are three important points which should be considered in all foundations:—

1st. That the weight to a unit of area imposed upon it should not be more than it and the subsoil below it can bear.

2nd. That it should be as nearly as possible homogeneous and equally strong throughout.

3rd. That the upper surface should be horizontal: if not in one, then in several planes.

*Foundations particularized.*

1. Rock, gravel, and such unalterable grounds.
2. Clay, sand, and such alterable grounds.
3. Firm ground underlying soft ground.
4. Firm ground overlying soft ground.
5. Soft ground of indefinite thickness.
6. Concrete.
7. Fascines.
8. Piling.
9. Hollow cylinders.
10. Foundations in water.
11. Loose stones.
12. Coursed masonry and concrete.
13. Caissons.
14. Coffer-dams.

*Rock.*—It is generally supposed that rock is a dangerous substratum to make a foundation platform from; for it is rarely that rock is found so homogeneous as to provide a large horizontal surface without artificial filling in; and it is difficult to make the filling in as hard as the rock itself, which it should be, that the settlement, if any, may be uniform. Also in many cases of inclined strata there is the danger of one part of the strata slipping over the other from the additional pressure of the building.

*Renaud*, from experience, recommends that a foundation in rock should never be less than $0^m \cdot 3$ in depth, for security against slipping and detrusion.

*Hughes* gives an example of a pier of an aqueduct 50 ft. high, which being founded partly on rock and partly on gravel, was split, owing to unequal settlement.

*Gravel.*—Many consider a sound thick stratum of gravel to be the most secure foundation possible. In such cases it is only necessary to sink a little into the stratum, rather more than into rock, and to take care that the area of foundation is proportional to the weight a square unit the gravel is calculated to bear. When the gravel is not sound, besides the latter precaution, it is advisable to sink deeper and fill in with an artificial foundation of concrete or large stones or hard durable timber.

*Sand.*—When in thick strata, and not liable to be moved by water or other disturbing cause, sand forms a very good foundation; it is desirable to sink deeper into sand than into gravel, and to fill in with an artificial foundation to counteract any irregular settlement of the sand. When exposed to the action of water or any other moving action, however slight, sand is a dangerous foundation to trust to, on account of its great mobility.

*Clay* appears to be considered an uncertain and troublesome substratum for a foundation, on account of the irregularity of its strata, and its action on being disturbed; for there is a tide in the land as well as in the sea. In consequence of clay's plasticity and its retention of water, it is liable to yield unequally to the pressure of a building, and to move irregularly when exposed or cut into: consequently, care must be taken both to spread the structure over a large area of foundation and to load the foundation uniformly in the course of the construction. Dobson gives examples of the expansion of clay on exposure to air by cutting and also on saturation with water. In the Box-hill Tunnel 6 in. was allowed for the expansion; and in the Metropolitan Railway the expansion of the clay on cutting had to be provided for in the centering and staging. A bed of clay can be sometimes made firmer by piling or by making holes in it and filling them with stones or gravel: the elasticity of clay is sometimes so great that Renaud states that piles are often forced up again by the action of driving the neighbouring piles.

It frequently happens, especially in the alluvial banks of rivers, that below the soft ground of the immediate surface lies a hard stratum, and when the thickness of the soft superstratum is not great (30 ft. may be considered a maximum for ordinary cases), a secure foundation may be obtained by carrying piles or piers down to the hard ground below and supporting a horizontal platform on their tops. These may be wooden or iron piles driven till they enter the hard bottom; or piers formed by sinking well-holes through the soft ground and filling them up with masonry, loose stones, or, Renaud says, even sand, though this last should only be used when the superstratum is sufficiently firm to resist the lateral pressure of the sand. The tops of these, if piles, may be connected by beams and planks forming a horizontal platform; or if piers, by arches filled in at the spandrils to a horizontal surface. These piles or piers must be considered as columns fixed at the bottom and calculated accordingly, without trusting to the lateral support of the intermediate strata.

*Firm Ground overlying Soft Ground.*—In some cases of alluvial foundations, a stratum comparatively firm of gravel or clay is found at the surface or near it, the substrata below that being much softer. In such cases, if the weight of the structure is not very great, it is frequently desirable to leave the hard crust unbroken; but then the area of foundation should be enlarged, beyond what would be used for the same stratum, if of considerable thickness; and special care should be taken to distribute the pressure equally. Also in these cases the hard crust should be cut into as little as possible for any purpose; if it is clay there is danger of it yielding by exposure to air and wet; if the substratum is sand there is danger of its being moved by the action caused by drainage or any operations of that kind, consequent on the building.

*Soft Ground of Indefinite Thickness.*—When the soft superstratum is of indefinite or very great thickness, and not hard enough to *float* the building upon it, by extending the area of the foundation, it must be supported upon piles or piers, carried sufficiently deep that the friction on their sides will be enough to carry the weight. In the case of piling, they should be closer together than in the former case, and the heads of the piles, besides being connected together with timber framework, should be surrounded with a mass of masonry or concrete, to distribute the weight and add to the resistance. If piers are employed they may be of masonry, sunk in the manner that wells are formed, and which are used as foundations by the natives in India, or they may be hollow cylinders of iron.

When the ground is exceedingly soft, there is considerable danger of the pressure on that part underneath the building causing that part surrounding it to rise above its original level; to counteract this, as far as possible, the piling or piers should be extended beyond the area of the foundation, and the ground in the immediate neighbourhood should be consolidated or weighted with stones or concrete, and as few excavations as possible should be made in the natural soil. It is also necessary in these cases to equalize the pressure all over the area of the foundation, because there is sure to be a settlement, however small, and the smallest irregular settlement will cause a break in the structure. Equalization of the pressure on the foundation will not, however, prevent an absolute settlement, nor a rising in the neighbouring ground, which latter can only be counteracted by piling and counterbalancing the pressure by weighting the surrounding parts.

*Concrete.*—The nature of concrete that should be used for a foundation depends on the nature of the soil it is to be laid in; the object in all cases being to get as nearly as possible a homogeneous bed under the structure. If the soil is dry, a concrete of sand, gravel, and as much ordinary lime as is necessary to produce a coherence of it altogether is sufficient; as it is little more than a bed of coherent gravel; but then it must be spread over such an area that it might be sloped at an angle of 45° from the outside of the footings of the walls, down to the bottom of the foundation; and of such a thickness that it will not be liable to crack under the pressure. For ordinary buildings probably from 2 to 3 ft. is sufficient. If the soil is wet, or the building is of great weight or special character, the concrete should be made of hydraulic lime and sand and broken stones, in about the same proportions as would be used in rubble masonry; that is to say, the lime should be about $\frac{1}{7}$, the sand about $\frac{2}{7}$, and the broken stones about $\frac{4}{7}$. These, however, must be considered only as average proportions for medium hydraulic lime and ordinary wet soils; the proportion of lime must be varied inversely as its quality is better or worse, or as the circumstances are more or less important. In such cases the concrete, if properly constituted and laid, may be considered as a solid coherent mass, capable of bearing without crushing the weight the square foot mentioned in recognized tables as the crushing resistance of different kinds of concrete, a proper coefficient of safety being used. The bed of concrete must also be thick enough not to break by transverse strain, but so as to settle in one mass if the subsoil yields. These two considerations will determine the area of the bed for the foundation.

With moderate hydraulic limes and common limes there will be an expansion of the mixed concrete, consequent on the slaking; in some cases the lime increases to double its original bulk; this may be almost entirely provided for by allowing time for the lime to be thoroughly slaked before laying the concrete; in some cases, however, the lime, or parts of it at least, will take so long to slake, that the process is completed after the concrete is laid, and it is therefore generally desirable to consider this expansion in preparing the site for the concrete.

As the principal object in laying a bed of concrete is to form a solid cohesive mass when it hardens, it has been sometimes recommended that it should be thrown in from a height to consolidate it; this practice, however, has the disadvantage of separating the fine from the coarse particles: it is better to lay the concrete from barrows or boxes on the level of the site, and to consolidate it afterwards by ramming; in ordinary foundations, to effect this properly and to allow the lime to set, the concrete should be laid in strata of not more than 1 ft. thick each; it is very desirable to bond these strata into each other in the process of laying, as the joint between two days' work is always a weak part in the mass. In large foundations, or with strong hydraulic lime, it is better to make the strata 2 or 3 ft. thick; on that account, for the same reason, the whole of one strata should be laid as quickly as possible.

In large foundations in water, a slight coffer-dam is generally made round the area required; if there is rock underneath, the coffer-dam is made of framework filled in with sheeting; the soft ground is then dredged out from the inside of the coffer-dam, and the space is filled with concrete to the height at which the regular masonry begins, which would be generally at 3 or 4 ft. below the lowest water-line. In this method the concrete is generally lowered into the water within the coffer-dam, in a box with a movable bottom, which is made to open when the box is near the place required, and so allow the concrete to fall gently into its position; of course, a strong hydraulic lime must be used, and therefore the concrete should be laid as quickly as possible in a mass.

*Fascines.*—In soft marshy ground of great depth, a foundation of fascines is frequently employed in places where suitable brushwood is plentiful, in Holland for instance; and in such places it is highly approved of. Its recommendations appear to be that when carefully made it is elastic, durable, and uniform.

Authorities differ as to the best size of fascine for foundations; Pasley recommends 6 in. diameter; Lewis used them 12 in. diameter successfully, as a foundation for a 3-gun martello tower at Hollesley Bay on the coast of Suffolk, built in 1812. Hughes, U.S., says that on the Dutch railway from Amsterdam to Utrecht, they used two kinds, a saucisson of $0^m \cdot 4$ circumference and a fascine of $0^m \cdot 5$ circumference. But all agree that they should be compactly made of carefully-selected wood.

When the sward of a site of the town was removed, preparatory to laying the foundation, speaking of the operations in Holland, the ground was found so soft, that a 10-ft. rod was easily thrust down the whole length of the rod with the hand.

*Extract from Paper by Hughes, U.S.—Description of the Fascine Foundation of the Embankment of the Amsterdam and Utrecht Railway.*—The fascine foundation is to be formed by an under and upper framework of hurdles (*saucissons*) $0^m \cdot 4$ thick, with a backing of fascines between them. Including the second layer of *saucissons* of the under frame, and the first layer of the upper frame, the mean depth of the backing ought to be $0^m \cdot 5$. The *saucissons* to be of a uniform texture of straight sticks, strongly connected together by not less than eight twig bindings for every mètre in length. Those of the first layer of the under frame to be placed lengthways, in the direction of the road, at 1 mètre central interval; those of the second layer at right angles to the first, also at 1 mètre central interval. The longitudinal *saucissons* to break joint; the two layers to be tied together at every crossing with strong twig bindings. Upon this under frame, which must be well filled up with sand to the level of its upper surface, are to be laid the first course of fascines; then two transverse layers crossing the first at right angles; and on this a fourth layer, like the first, at right angles across the axis of the way, but having the larger ends of the fascines turned to the other side: they are to be well rammed together. The packing must have a depth in the centre of $0^m \cdot 6$, and at the side $0^m \cdot 4$. The upper frame, of the same construction as the lower frame, to be placed over it, so that the upper layer of *saucissons* comes parallel to the axis of the road. Through each crossing, stakes are to be driven, passing through the hurdles of the under frame.

The fascines to be made of sound and clean willow wood of not less than three years' growth, or of oak brushwood of not less than five or six years' growth; the wood to be straight and cut green last season, to be firmly bound with two bindings and well tightened. The length to be $3\frac{1}{2}$ to $4\frac{1}{2}$ mètres.

*Piling.*—There are two modes in which piles may be used to form a foundation:

1st. *When the soil is soft for a considerable depth;* in which case a large area should be covered with piles connected together by framework at the top, and so forming one united body, which would resist settlement chiefly by the friction of the subsoil against the sides of the piles.

2nd. *When there is a stratum of hard ground below the soft;* in which case the piles should be driven into the hard stratum and each pile would act as an independent column bearing a certain proportion of the whole weight, and resisting settlement both by friction and by its own transverse strength.

1st. *Soft ground throughout.*—M. Renaud says the piles should be from $0^m \cdot 8$ to $1^m \cdot 2$ central interval, which agrees with the general practice in England; they should be at that interval both ways, that is, the area should be studded with piles 1 yd. apart both ways; in England the size of piles is generally determined by the size of the logs or balks in which pine timber is sold in the market, and which are about 12 in. square on the average; a pile made of one such piece is commonly called a *whole pile;* when one such balk is cut into two piles they are called *half piles.* M. Renaud says the diameter should be $\frac{1}{24}$ of the length, and never less than $0^m \cdot 18$. Mr. Dobson recommends the area to be enclosed with sheet piling before the main piles are driven, in order to consolidate the ground better; he says soft clay is too compressible to be well consolidated by piling; it is so elastic that sometimes a pile is forced out of the ground by the driving of a neighbouring pile.

When the tops of the piles are connected by timber, Dobson says the first pieces should be those across the breadth of foundation, and the longitudinal pieces running parallel to the length of foundation should be over them: on these latter, planking should be laid to carry the masonry; it distributes the weight better to lay the planking diagonally. When the upper stratum of the ground is very soft, or when the timber framing at the top is fixed at considerable intervals, the upper part of the ground should be taken out and filled in with stones, or concrete or regular masonry, to increase the resistance of the piles and to form a more uniform platform for the superstructure; when of concrete, this top filling-in should be about 3 ft. thick for large buildings not excessively heavy.

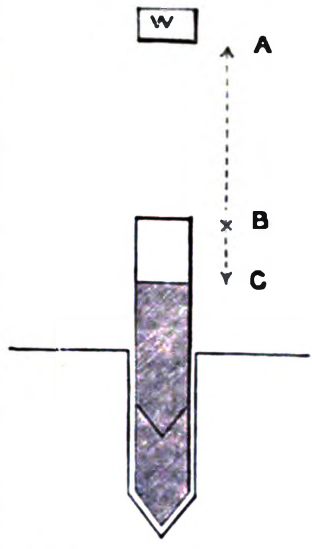
2nd. *Hard ground below.*—In this case, as each pile resists partly by its resistance to deflection, the diameter or cross-section should be greater in proportion to the length: when the depth is considerable, say above 25 ft., and the weight of the structure is considerable, two or more piles should be driven close together and well connected together at top; the piles should come immediately under the weight to be borne, and their number should be determined from that weight, and the timber framework at top should be strong and well tied together. It is advantageous in this case to arrange the superstructure of the building so that it may be ultimately carried on piers at intervals, and consequently that piling will only be required underneath those piers. It is evidently of great consequence that the piles should be quite vertical.

Various kinds have been used when the piling was of uniform character in straight lines, and when labour was expensive. Nasmyth's steam pile-driver has been used in England; it is an ingenious adaptation of his steam-hammer; the steam-cylinder rests on the head of the pile, so that the action of raising the ram tends to drive the pile down, as well as the fall of the ram itself. Another and more common mode of applying steam is by making the steam work an endless chain, which passes over a pulley at the top of the driving machine and round an axle at the bottom; the chain is made so that it lays hold of the catch of the ram by a self-acting apparatus. It is released at any height required in a similar manner to that of the crab-engine, and immediately on coming to rest on the pile is caught by the endless chain again.

The upright part of the pile-engine must be truly vertical when the pile is to be vertical, because the ram is guided in its fall by the two uprights; when the pile is to be driven in an inclined position, if the framing of the engine admits of it, the guiding pieces should be inclined accordingly, but if (as is usually the case) the framing does not admit of it, temporary guiding pieces must be laid against the uprights to the slope required, and the ram must work in them.

The statical weight which any given pile will support, without sinking, may be theoretically calculated from knowing the effect upon it of a known ram falling a known height. If the weight of the ram be $w$, and the weight of the pile $p$, and the fall of the ram be A B, Fig. 2054, and the distance through which it has driven the pile be B C; then the velocity of impact is $v = \sqrt{2g\,\mathrm{A\,B}}$, and the velocity with which the pile and ram move on together is $v_1 = \frac{w}{w+p}\,v$. Then the weights $w + p$ have passed through the space B C with a velocity commencing with $v_1$ and decreasing to $o$; therefore the accelerative velocity of the motion is $\left(\frac{(2\,\mathrm{B\,C})\,w}{w+p}\,v\right)^2$, and as forces are proportional to the velocities, they generate in a unit of time; then $g : w + p :: \left(\frac{(2\,\mathrm{B\,C})\,w}{w+p}\,v\right)^2 : \mathrm{P} :: \mathrm{P}$ being the pressure which would generate the accelerative velocity, and, consequently, the statical pressure which the pile will bear without moving farther.

2054.




This calculation is more applicable to piles which resist by the friction on their sides; it is applicable to those which are driven through very soft ground into a hard substratum, but in this case, in addition to this calculation, a further one should be made, considering the pile as a column fixed at its lower end, and liable to break by deflection.

M. Renaud has given an empirical rule which will serve as a guide. He says, first of all, that piles of a diameter of $\frac{1}{24}$ of their length will carry $0^{k}\cdot5$ a millimètre square; this must mean resistance to deflection, or crushing the wood. He also says, if a ram of 600 kilogrammes falling from a height of $3^{m}\cdot6$ drives a pile $0^{m}\cdot03$ in ten blows; or if the same ram falling from a height of $1^{m}\cdot2$ drives it $0^{m}\cdot01$ in thirty blows; then in either case the pile will bear 25,000 kilogrammes permanent statical weight. By which it is apparently supposed that the statical resistance varies directly as the square of the fall and weight of ram, and inversely as the depth driven in by a blow. He does not, however, place much dependence on his formula, for he recommends a practical experiment to be made in each case.

Pasley points out that if a scarp revetment 30 ft. high is built on piles 3 ft. apart each way, each pile will carry about 10 cub. yds. of masonry and about 3 cub. yds. of earth; and taking the former at 160 lbs. and the earth at 100 lbs. the cubic foot, the total weight on one pile will be 51,300 lbs.

He also says that at Neuilly Bridge, the arches of which are 128 ft. span, the weight of masonry on each pier is 15,417,648 lbs., which is borne by 135 piles. Therefore the weight on each pile is 114,200 lbs. They are of oak, 12¾ in. diameter and 13 ft. long.

Also, that Perronet considered that oak piles 9 in. diameter should not be loaded with more than 50,000 lbs.; and if 12 in. diameter, with 100,000 lbs.

Also, at the Bridge of Tours, one pier which gave way was on sixty-five piles of oak 8 ft. long, 9¾ diameter, and carrying each 166,212 lbs., the toe of the pile being in firm soil.

The tops or heads of wooden piles are generally protected from the action of the ram by an iron hoop, the head being cut round for the purpose. The foot or toe of the pile is generally shod with an iron-pointed shoe to save the wood. Cast-iron shoes are recommended in preference to wrought iron by some engineers, because it is more difficult to make the wrought iron to fit the toe of the pile exactly, which it should do to save the wood fully. The fastenings of the cast-iron shoe should be of wrought iron.

Wrought-iron piles have been generally used in the form of hollow tubes, and the mode in which they have been driven in England has been by attaching a broad-bladed screw at the end, and weighting the pile when vertical, and turning it by an apparatus at top, and thus screwing it into the ground. This method is only applicable in sand or soft soil. The chief difficulty appears to be to keep the pile vertical. In the 'Minutes of Proceedings of the Institution of Civil Engineers' for 1848, is a description of Mitchell's wrought-iron screw-piles, as used at the Southend Pier.

*Hollow Cylinders.*—As before mentioned, in soft soil of indefinite thickness, or sometimes when it is desired to reach a hard substratum, the superstructure of the building may be supported on piers at intervals, the foundation of which consists of hollow cylinders of masonry or iron, extending to the depth required, and sustained chiefly by the friction on their sides. The mode of sinking these cylinders is by excavating the soil from the inside, and allowing them to sink by their own weight, in the manner in which the *steining* of masonry wells are formed. The practice appears to have been long in use in India, where it is the custom to sink many of these masonry wells over the area of the foundation required, and connect them at the top by arches or flat stones. Owing to the use of iron, the English engineers have been able to enlarge upon this method, and it has become a common method of obtaining foundations for piers of bridges and such structures

in water. When they are applicable, they are economical and expeditious, and they can be carried to great depths. They are generally made of cast iron, but the largest cylinders are of wrought iron. They are generally made of from 5 to 10 ft. diameter, and in lengths of from 6 to 10 ft.: probably 3 ft. diameter is the smallest size that could be used, and sometimes they are of much larger diameter. The soil inside is excavated by hand labour; therefore in passing through watery soil it is necessary to keep the water out, which is done by forcing into it a pressure of air sufficient for the purpose. There must in such cases be an arrangement of air-tight partitions across the interior of the cylinders with trap-doors in them for the passage of men and materials, for the men are working, like in a diving-bell, under a heavy pressure of air. M. Renaud mentions a cylinder foundation at Bordeaux, on the Gironde, a gravelly bottom movable by floods; the cylinders were $3^m \cdot 6$ diameter. There were $13^m \cdot 35$ of water, and $7^m \cdot 5$ of foundation below that, making a total pressure of $20^m \cdot 85$. The thickness of the cast iron was $0^m \cdot 04$. The joints were planed, and had a ring of india-rubber between them, laid in a groove in the joint. In this case the cylinders were forced down by hydraulic pressure. He also mentions a foundation in the Rhine at Strasburg, consisting of a cylinder of wrought iron, 7 mètres diameter and $0^m \cdot 008$ thickness of metal, the depth of water being 11 mètres and total depth of cylinder 17 mètres. It was filled with concrete.

The centre pier of Saltash Bridge, near Plymouth, rests on a wrought-iron cylinder, 37 ft. diameter and 70 ft. deep from the surface of the water. The cylinder rests on trap rock, and is filled with granite masonry.

It is the general practice to fill the interior of the cylinder with cement or masonry, so that when the iron is destroyed by rust the masonry column will resist by its own strength.

*Foundations in Water.*—The difficulties in making foundations under water, which are added to the ordinary difficulties on land, are, 1st. The presence of water, impeding all operations; 2nd. The stratum of mud or gravel generally found on all beds of streams; 3rd. The danger of the foundation being undermined by the current. There are five different methods used for making foundations in water, so as to meet these difficulties.

1st. By piling or cylinders.

2nd. By throwing in loose stones to form an artificial bank up to the surface of the water.

3rd. By using a diving apparatus, and building regular masonry under the water.

4th. By sinking a box or caisson of the size of the foundation required, and building inside it.

5th. By enclosing the area of the foundation in a coffer-dam, and pumping the water out of it.

Before the introduction of iron cylinders and of the use of concrete so extensively, the ordinary method of obtaining a foundation for the piers of a bridge was by piling under the area of the pier, and cutting off the piles as low as the water admitted, and planking over the tops of them to form the platform. To prevent the current, increased by the obstruction of the piers, from carrying away the soil about the piles, a mass of loose stones was generally laid round the upper part of the piling; but this was not always efficacious in strong streams with soft bottoms. In such cases M. Renaud recommends that the area of the pier should be enclosed with sheet piling and filled in with concrete. He mentions an example of a difficult case of foundations in a stream with a bed of moving gravel, at Moulins, on the Allier. Three bridges had been carried away by the undermining of the foundations. A flat bed of masonry, $1^m \cdot 65$ thick, and 1 mètre below low water, was laid on the gravel from bank to bank for a length on the stream of 34 mètres, and protected above and below stream with a wall. Several of the bridges over the Thames at London have given way in consequence of the undermining of their pile foundations by the increased current caused by the improvements in the river. Therefore piling is not used now generally, except for long sea-walls and in special cases.

*Loose Stones.*—By this method masses of loose stone, just as taken from the quarry, are thrown into the water from a stage built on piles over the area of the foundation required, and are left to find their own position of equilibrium. It is therefore a method chiefly applicable to breakwaters, moles, and such extensive sea-works. The principal point for consideration is the size of the stones to be used in the different parts of the work. As the action of waves is greatest near the surface, and, according to experiments made in the Gulf of Lyons, does not extend below 24 to 30 ft. even during hurricanes, the smallest stones should be placed at the bottom and the largest at the top. In forming the foundations for the walls of the Basin Napoleon at Marseilles, the French engineers laid down precise rules for these sizes. The stone was a limestone, and they divided all that came from the quarry into the following four classes:—

| | | | | | | |
|---|---|---|---|---|---|---|
| 1st. | Rubble, | in pieces | weighing from | 5 to 100 | kilogrammes | each. |
| 2nd. | Blocks | ,, | ,, | 100 to 1300 | ,, | ,, |
| 3rd. | Blocks | ,, | ,, | 1300 to 3900 | ,, | ,, |
| 4th. | Blocks | ,, | ,, | 3900 | ,, | upwards. |

And the following proportions of each class were used:—

| | |
|---|---|
| 1st. | $\frac{2}{5}$ |
| 2nd. | $\frac{2}{5}$ |
| 3rd. | $\frac{1}{5}$ |
| 4th. | $\frac{1}{5}$ |

Dobson quotes from Poirel's account of a mole constructed at Algiers in 1841, of loose stones, of which the minimum size was from 18 to 27 cub. ft., and the general size under 100 cub. ft. It was found that up to a level of from 13 to 16 ft. below low water the stones preserved a slope of 1 to 1, or 1 height to $1\frac{1}{2}$ base, and above that level they preserved a general slope of 1 to 6 and 1 to 10, becoming flatter nearer the surface; but that nearer the surface the stones never rested long in one position, but were altered by every storm.

In building a superstructure of regular masonry on the top of a foundation of loose stones, it is

desirable that the junction of the regular masonry with the loose stones should be well covered on the exposed side to allow for the subsequent movement of the stones.

The breakwaters of the harbours of refuge at Portland and Holyhead are excellent, and remarkable examples of foundations of loose stones in water.

*Regular Masonry.*—In places where squared masonry is not expensive, or where, from circumstances, it is necessary to have a vertical face to the foundations and walls, the foundation is sometimes built up from the bottom in regular masonry, with the help of a diving-bell or other diving apparatus. It is advantageous, when practicable, that sea-walls should have vertical faces (or nearly vertical) to a depth of 20 or 30 ft. below low water, because the waves will not break generally in that depth, and the wall would in that case have to resist only the oscillating action of the waves, and not the progressive action. With the assistance of a diving apparatus, the process of construction is carried on in much the same manner as on dry land. The bottom is levelled, and any superficial strata removed, and the stones are lowered and placed singly; of course a strong hydraulic lime must be used for the mortar.

*Caissons.*—In this method a large case or box (called a *caisson* in France, which name, from the more frequent use in that country of this method, has also been adopted in England), is floated over the area of the foundation, and sunk by building the foundation inside it; as it sinks, the sides of the caisson are also carried up sufficiently high to keep out the water, and thus the great box containing the masonry gradually sinks to the bottom; the bottom must be levelled and prepared for it beforehand, with the help of a diving apparatus. The caisson has been generally made of wood, but wrought iron has been used. Renaud calls it a great flat-bottomed boat, and says the method is applicable to deep water. Both he and Dobson agree that the great difficulty is in obtaining a hard level surface for the bottom of the caisson to rest upon. Any soft strata should be dredged away; and if the surface is irregular, a bed of hydraulic concrete should be laid over it; if the natural bed is too soft to carry the caisson, piles must driven over the area, and a platform of concrete or planks formed on the top of them for the caisson to rest on.

*Coffer-dams.*—When circumstances require that a perpendicular wall should be built in not very deep water—say 20 ft.—and when there is good holding ground for piles, and the area of the foundation is not very large, then it is a very efficacious method of obtaining a foundation, to enclose the area with a temporary water-tight wall, and pump out the water from the interior, and proceed to form the foundation, as if it was on dry land. This temporary water-tight wall is commonly called a *coffer-dam*, and is generally made by driving two rows of piling, about 4 ft. apart, the piles in each row touching each other, and the space between being filled up with clay. In constructing the coffer-dam, a row of what are called *guide-piles* are driven along the line of the coffer-dam; they are generally made of *whole timbers*, and are at, about, 10 ft. intervals; on the inner (or coffer-dam) side of these, two longitudinal timbers are fixed, called *wale-pieces*, one as low down as the water will permit, and the other near the top, thus connecting the guide-piles together: inside of and close against the wale-pieces are driven what are called *sheet-piles*, about 3 in. thick and of the breadth of whole timbers, driven as close together as possible. At about 4 ft. distance, another row of guide-piles, wales, and sheet-piles is formed, the sheet-piles being on the inner side, so that the two rows of sheet-piles form a long narrow deep trough; from this trough the natural mud or sand must be excavated by dredging down to some impervious stratum, and must then be filled up to above the highest water-line with an impervious clay, well worked and kneaded into its place, which working is generally done by men's feet: the clay so worked is commonly called *puddle*. This is a general description of a good-sized coffer-dam, but the dimensions of its part must vary with the size and circumstances of the whole; and it may be made sometimes without piling, and sometimes the rows of piles may require additional piles, and braces, and struts, to resist the pressure of the water. For when the water within the area of the foundation is removed, the piles of the coffer-dam will be in the condition of beams fixed at the lower end, and subject to a transverse strain arising from the pressure of the water acting at its centre of pressure. The principal points to be considered in using coffer-dams are:—

In soft ground there is danger that before there is any weight put on the area of foundation, it may be forced up by the pressure round the outside of the coffer-dam.

It is very necessary that the piles should have good hold into a sound substratum. There is always great danger of leakage between the bottom of the puddle wall and the natural bed of the water; leakage through the puddle is also to be guarded against; sometimes gravel is mixed with the puddle to lessen its tendency to crack, and so leak. Springs of water arising from the ground inside the foundation area should be provided for by draining to a suitable spot and pumping. It is probable that after the water inside has been removed, a pump will have to be kept constantly at work to keep down leakage and springs. The clay for the puddle wall should be cut small and well rammed or *punned*, as it is called, in layers.

Coffer-dams have been much used in England for foundation work in water, because it enables the bottom to be well examined and carefully prepared for the superstructure. It is an expensive and laborious method, because a part of the piling has to be driven from barges, and because of the puddling.

Sheet-piles must be shod and capped similarly to other piles: their toes are generally cut with a bevel or incline, forming a point, which in driving is placed next the last driven pile, so that the pressure against the bevelled part in driving forces the toe close to the last pile.

Sometimes coffer-dams are only used to form *shores* or revetments to the sides of the area of foundations, and the water is not removed; then the soft strata required to be removed is dredged out, generally by hand dredging; and the foundation is formed by putting in hydraulic concrete in mass between the rows of piling of the coffer-dam.

*Walls.*—A wall of a house has two duties to perform: *First*, to support the floors and roof; *second*, to screen the interior from the weather. These two duties should be always clearly distinguished in considering the construction of every wall. For the first duty, it will generally be

sufficient that the wall should consist of piers or columns at intervals, extending in an unbroken perpendicular line from roof to foundation. For the second duty, the spaces between these piers may be filled in a slighter manner, and even with different material, because the utmost pressure this part of the wall has to carry is that of its own weight, and part of that may be frequently thrown upon the piers. In ordinary dwellings these two parts are generally united into one common thickness of wall, in which apertures are left for the doors and windows; but it is not less necessary to keep them distinct in the mind, and to ensure that the solid blocks between the apertures, which are the real piers carrying the whole weight of the structure, extend in an unbroken line from roof to foundation, and that the spaces above and below the apertures have as little weight to carry as practicable.

*Squared Masonry.*—Stone walls are built sometimes of regularly *squared masonry* laid in uniform horizontal courses; sometimes of masonry only roughly squared and laid in courses, horizontal, but not regular, and which is technically called *Random rubble;* sometimes of rough masonry without any courses, but roughly shaped to fit into each other, and which is technically called *Uncoursed rubble;* and sometimes of rubble faced with squared masonry, and which is technically called *Ashlar.* The choice of either of these modes of building must depend on the material available, and the object of the work. For walls of dwellings the first method is the strongest and most certain. With such masonry the mortar or cement should be of a fine description, and only sufficient of it used to make a layer between one stone and another, as the main strength of the wall depends on the bonding and mutual pressures of the stones, and the chief object of the mortar is to ensure the pressures being distributed over the surface.

The danger to be apprehended in stone walls of square blocks is that the blocks will not press evenly on the beds of their courses, and so cause fracture of a stone; therefore stones should not be too long, compared with their breadth. Of whatever the quality of stone, the wall should consist of as much stone and as little mortar as possible.

The courses of such masonry should be horizontal and of equal or nearly equal heights: the horizontal joints in a wall may extend through it, as the pressures are generally vertical, but the vertical joints should be broken both transversely and longitudinally, otherwise the wall approximates more or less to the condition of an assemblage of thin columns. Subject to this condition, it is immaterial, as far as construction is concerned, where the vertical joints occur. *Bonding* is the technical name for breaking joint so as to connect the parts of the wall into one mass as much as possible, and where it occurs regularly the stones are called *headers* and *stretchers;* occasionally a *through bond stone* should occur extending through or nearly through the wall. Renaud recommends that the length of stones in squared masonry should not be more than four or five times the height: and Hosking recommends that the *through bond stones* should not be very long, but extend only about ⅔ through the wall, laid alternately from each face. Tredgold recommends that even through bond stones should not be more than three times their thickness in length. As a general rule, the stones should be cut with the natural quarry-bed horizontal.

*Rubble masonry, if coursed,* is subject to the same general conditions as squared masonry as respects bond and joints. More mortar is necessary, on account of the greater irregularity of the surfaces; for the stone is only roughly dressed with the hammer and chisel, and the stones being of irregular sizes, the horizontal joints are broken; therefore the bonding is not so regular nor so good, and more through bond stones are required. This description of walling is, therefore, more suited for thicker walls than the squared masonry; it is very effective when the stone is of a highly-stratified character and capable of being roughly squared without much difficulty. It was much used by the Gothic builders, who had a difficulty in obtaining large blocks of squared stone. Squared masonry is the exception in Gothic buildings, and is used for columns, groins, and such like principal parts, the main body of the walls and arches being filled in with rubble in random courses.

*Uncoursed Rubble Masonry* is the term applied to masonry of unsquared stones, roughly dressed to fit into each other, and therefore without regular horizontal or vertical joints. It requires higher skill to build such a wall well, than one of horizontal courses, to fit the stones properly into each other, and so make the wall as much as possible one mass of tightly-wedged stones; therefore, it shows a skilful builder to build a dry rubble wall without mortar; but uncoursed rubble requires more mortar than coursed and of a better quality, for as there is a greater liability in the wall to slip over its joints from the vertical pressures, a greater part of its strength depends on the resistance of the mortar to shearing. It is a method most suitable with unstratified stones having irregular planes of cleavage, and it should be the object in fitting the stones together to make use of those natural planes of cleavage.

This method was first used in what is called cyclopean or polygonal walling, which, in the Mediterranean, was of large blocks dressed to the form of the natural cleavage, sometimes with care, and so fitting closely without mortar, and forming a very strong wall, though expensive in labour. Many of the old Venetian walls in the Mediterranean and also Gothic walls in many places are built of small stones in this manner. The stones should be of uniform size, with bond stones to tie the two faces of the wall together. But the most usual and efficacious mode of bonding a wall of this masonry is by horizontal bands of a few courses of squared masonry or of brickwork extending through the thickness of the wall and all round the building. Such a method was commonly employed by the Romans; walls of rubble-work, sometimes very rough, sometimes no better than coarse concrete, and alternated with bands of the thin Roman brick, constitute a general type of Roman masonry. M. Renaud says the intervals of the courses of bricks were from 1 mètre to $1^{m}\cdot4$.

But the most advantageous employment of this description of masonry is in revetments and such like walls of fortifications. Such walls are generally of considerable thickness, and have generally only one fair face—two favourable circumstances for its use. If well built with stones of nearly equal size and with good mortar well filled in, it offers a better resistance to artillery fire than

squared masonry, unless of very superior description. It is necessary in such cases to put a facing to the wall of rather larger and more regular stones, and to make the exterior face perpendicular, in order to avoid the growth of vegetation on it. Renaud says truly that in all masonry of small pieces the bond is not so important as the mortar and the care of execution.

*Brickwork.*—If the stones of a wall of squared masonry were obliged to be all of one size, then, in order to ensure the effective bonding in the horizontal courses, the length of the stones should be double the width; then the stones in one horizontal course would be laid lengthways and in the next course crossways, or, as it is technically called, *stretchers and headers.* See BOND.

*Mortar.*—The mortar and the workmanship are of more consequence in brickwork than the bricks themselves. If the pressures on a wall were always exactly vertical, then all that is required in the building would be to distribute those pressures over the parts intended to carry them; but there is almost always a liability of inclined pressures on all walls, and a certain inclined pressure on many: hence the mortar is subject to a shearing strain, and much of the efficiency of the wall depends on its strength and adhesion to the bricks. This is particularly the case in walls of fortifications exposed to artillery fire. It is invariably found in cases of breaching brick walls by artillery that the brickwork is shaken for considerable distances beyond the actual rupture, and that the line of shake almost always follows the joints. The line of pressure in this case being nearly horizontal, the only resistance to motion besides the weight of the portion of the wall is the resistance to shearing of one or more joints of brickwork. Hence it is especially important in walls of brickwork and squared masonry so exposed to arrange them in large masses.

The proper thickness of the joint of mortar in brickwork must depend somewhat on the nature of the lime used. If the mortar is equal in strength to the bricks, the joints may be as large as the bricks, as was the case in the old Roman brickwork, the joints of which were from $0^m \cdot 02$ to $0^m \cdot 03$. This was partly on account of the thinness of the Roman brick compared with its area. When the mortar is inferior in strength to the bricks, as is generally the case, the less there is of it the better. Hosking recommends that with bricks $2\frac{1}{2}$ in high no four courses should reach $11\frac{1}{2}$ in., which allows less than $\frac{4}{10}$ in. for a joint. He also points out that thick joints of mortar (unless of superior description) are more liable to injury by wet and frost, and to cause a greater amount of settlement in the wall. The minimum size for a joint is simply that no two bricks should touch each other.

The necessity of using clean and moist bricks will be pointed out in our article on Limes and Mortars, and also the advantage of using stiff mortar, as compared with the more common practice of *Grouting*, which is the term used for a very liquid mortar poured over the wall at every one or two courses, with the object of filling up the joints thoroughly. Besides the evils of drowning the lime, and saturating the brickwork, and tempting the bricklayer to use wet mortar and dry bricks, it is evident from the foregoing considerations that a wall so built would not have as much resistance to shearing in its joints as one well filled up with stiff mortar.

*Secondary Parts.*—By the *secondary parts of walls* are meant cornices, string courses, window-sills, chimneys, and so on.

These are frequently made of stone, although all the remainder of the building may be of brick. The object of a cornice or coping, as far as construction is concerned, is to prevent wet from entering in the top of the wall. It should therefore project over the exposed face of the wall, and be sloped on the top, and hollowed out on the under-side, to prevent the water from running on to the wall; and it should be itself impervious to water. Stones, when used for such purposes, are generally connected together by metal *cramps* or stone *dowels*. A cornice or coping of brickwork should be made of bricks, specially moulded and burnt for the purpose, and set in hydraulic lime. The formation of a cornice by projecting courses (or corbelling) is subject to the same considerations as in footings; the pressures are exerted on the projections in a similar manner, but in the reverse direction. String courses are now seldom used, except for purely ornamental purposes, and for these it is only necessary to bed and bond the stones or bricks sufficiently into the wall to give them stable support. For constructive purposes, string courses are bonding courses in the wall itself, and should therefore go through the wall.

Window-sills are more frequently made of stone than any other of these parts, on account of the transverse strain they are subject to: in order to preserve the horizontal line, the sill is generally made in one piece, resting on the piers of the wall at each side, and not on the filling-in part between; otherwise there would be danger of fracture, owing to the unequal settlement of the piers and the intervening part. A window-sill is the coping of that part of the wall it covers, and should therefore be shaped similarly to a coping or cornice.

If there is no danger of irregular settlement the sill need not be made in one piece.

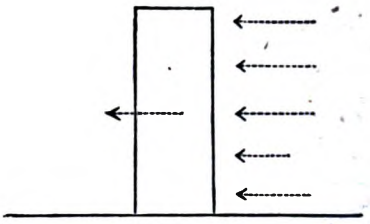
To provide a place for the fire and its flue in each room in climates where they are necessary, part of the wall is made thicker from the foundation; consequently, it is desirable to arrange the fire-places in the successive stories so as to come over each other. The space required for a grate for an ordinary room varies from 3 to 5 ft. wide, and about $1\frac{1}{2}$ ft. deep, and 3 ft. high, according to the size of room and grate; the wall at the back of the grate should be at least one brick thick. The sizes of the piers or *jambs*, as they are called, depend on the number of flues to be inserted in them; for the flue of each fire, after being *gathered* into a throat immediately above the fire, is diverted on one side to allow space for the fire-place of the next story above it. A flue, if built in brickwork, cannot easily be less than 9 by $4\frac{1}{2}$ in., and as there should be at least half a brick between each flue, and one brick on the outside of the outermost flue, the size of the jamb for a given number of flues is thereby determined. It is difficult to give precise rules for the arrangement of fire-places, because so much depends on the grate. The problem is to provide as easy an exit as possible for the products of combustion, and yet not more than they require. This is met theoretically by inclining the sides of the fire-place gradually to an opening close above the fire and calculated to be just large enough for the products of combustion; this part of the problem is generally provided for in the grate; it is like the sluice-gate of a water-mill, excepting that air,

being so much more delicate a substance than water, requires much more careful provision for its flow. After passing through the grate, it should be allowed to flow into the open air as regularly as possible: there is, therefore, an advantage in having very smooth sides to the flues; this is generally effected by plastering the inside of them with a special plaster to resist heat; it is common hair mortar mixed with cow-dung. A much better mode has been lately employed, by inserting glazed earthenware pipes in the wall, which gets rid of the objectionable corners of the brick flue, and of its unnecessarily large size. The large size of the flue both decreases the velocity of the stream of hot air, and allows cold air to descend and check the flow of it; the flue should decrease in size slightly as it ascends.

Carrying all the flues up together in one stack, or *chimney-breast*, as it is called, is both economical, and tends to preserve an equal temperature in them; for the latter reason, which is a most important one, brickwork is better for chimneys than stonework. But for the last few feet above the roof, each flue should be in a separate stack of its own, and as small as possible, for everything that obstructs the wind tends to produce a counter-current in the flue. No two fires should lead into one flue, unless they are always alight together, or a down-draught will occur probably in the one not lighted. No woodwork should be built into the chimney-breast or any part of the chimney for any purpose whatever.

*Thickness of Walls.*—The thickness of the walls of ordinary buildings, Fig. 2055, is more a practical than a theoretical question. As M. Renaud points out, the theoretical thickness to meet the vertical pressure only would be very small in any case. The rupture of the wall by separation of the joints would almost always take place before the crushing of the stone itself, and that force should, therefore, be provided for, or at least the two must be taken into consideration together. With squared stones the crushing would be the most probable, and in this case generally the safe weight is taken at $\frac{1}{10}$ the breaking weight. In rubble-work the tendency is to rupture of the joints, owing to the irregular pressures; the proportion of the safe weight to the breaking weight should therefore be less.

2055.



M. Renaud quotes the following theoretical rules from Rondelet for the thickness of walls of ordinary buildings:—

*For Isolated Walls,*

$$b = 12\sqrt{\frac{h}{s}}$$

where $b$ = breadth, $h$ = height of wall in mètres; $s$ = weight of cub. mètre of masonry.

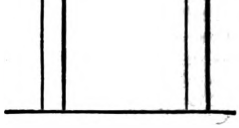
This rule is evidently based on the assumption that the force acting on the wall is similar to that of the wind, in which case the equation for overturning the wall would be $s.h.b.\frac{b}{n} = p.h.\frac{h}{m}$, where $p$ = force per unit of area of wind, and $n$ and $m$ are coefficients depending on the circumstances in each case.

*For Walls of Houses*, Fig. 2056,

$$\frac{l\,h}{\sqrt{l^2 + h^2}}$$

where $l$ = span or distance between opposite sides in mètres.

2056.



Which appears to be based on the assumption that the pressure on the walls varies as the span of the roof. The height $h$ in this case is to be taken between the floors or points of support supposing them to be of strong construction.

He states the following to be the usual thicknesses of walls in Paris; they are of squared masonry of limestone:—

| | Exterior Walls. Mètres. | Interior Walls. Mètres. |
|---|---|---|
| Houses 18 mètres high .. .. Walls tolerably close .. .. Floors 4 to 5 mètres apart .. | 0·5 | 0·4 |
| „ at top .. .. .. .. | 0·45 | 0·4 |
| Large houses .. .. .. .. | 0·6 to 0·8 | 0·43 to 0·5 |

The interior faces of the walls are always made perpendicular, and the *batter* or increase is always on the outside.

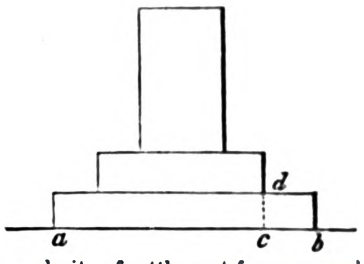
In London the minimum dimensions for walls of houses in streets is fixed by Act of Parliament, in order to provide for the strength and security from fire of rows of houses with common party walls. But these dimensions must not be taken as guides for military buildings of a permanent character; in such buildings it is not safe with the ordinary description of brickwork to make any wall less than 1½ brick thick; and, in accordance with the principle of the Act, an additional half brick should be added to the thickness for every two stories of height. This addition is generally made in England on the inner face of the wall, for the convenience of resting the beams of the floors on them. This is perhaps a better constructive arrangement than the French one, but it must depend upon the circumstances of each case which is adopted.

*Footings.*—In the process of constructing a wall, the mason or bricklayer first lays the *footings* on the foundation platform. The footing is an enlarged portion of the wall for the purpose of distributing the weight over the foundation: it is properly a portion of the wall and not of the

foundation, although it is not always easy to draw the line between them. When the pressures pass down through the centre of the wall, the footings may project equally on each side; when otherwise, the footings should be so arranged that the line of pressure shall pass nearly through the centre of them into the foundation. The size of footings and the mode of forming the increase to the thickness of the wall must depend on the circumstances and the material. For ordinary buildings Tredgold recommends that the extreme breadth of the footing, when the subsoil is clay or sand, be double the thickness of the wall; if on gravel or chalk subsoil, that its breadth to be that of the wall as 3 to 2.

Supposing the whole pressure per lineal foot on the wall to be equally distributed over the breadth of footing *a b*, Fig. 2057, then the reaction of the subsoil on the part *b c* will be equivalent to that proportion of the whole pressure, acting upwards and tending to break the projecting part *b c* about the section *c d*, which section must be strong enough to resist that transverse strain; in brickwork it is usual to make the projection of a footing for light buildings ¼ of a brick in every course, and for heavy buildings ¼ of a brick in every two courses. In stonework the proportional projection for a given height of course may be greater, according to the relative transverse length of the stone. The footings should always be made of large stones or of picked bricks, laid in very good mortar, and well bonded, with the object of distributing the pressure as uniformly as possible over the foundations. The foundation platform should, if possible, be in one horizontal plane, and the footings should be equal in height throughout the main walls of a building, in order to avoid, as much as possible, irregularity of settlement from unequal heights of wall.

2057.




The *Damp Course*, as it is commonly called, a course of some impervious material to prevent the damp rising from the ground through the masonry into the body of the wall. It is generally placed immediately above the footings, if these project above ground; but the damp course should be, if possible, 1 ft. above the ground. It generally consists of two or three courses of hard-burnt bricks laid in hydraulic mortar. A highly-burnt glazed hollow brick is made for the purpose, the perforations being horizontal, so that a current of air passes through the wall at that point. Perforated bricks are liable to crack under pressure.

### Table of the Pressures on the Footings of Walls.

From Tredgold, Encyclopædia Britannica, and Renaud.

Tredgold's Rule for breadth of walls $W = \frac{1}{3} f b d$, when $b d$ = area of cross-section of part of wall under consideration, W = safe weights in lbs. $f$ = tabular number = ¼th the splitting or ¼th the crushing force, in lbs. per square foot.

| Name of Building. | Value of *f*. Tredgold. | Pressure per square ft. Tredgold. | Pressure per square centim. Renaud. |
|---|---|---|---|
| | lbs. | lbs. | kilos. |
| Pillar of All Saint's Church, Angers, Forneaux stone .. .. | 110,000 | 86,000 | .. |
| Pantheon, Paris, pillar Bayneux stone .. .. .. .. .. | 62,000 | 60,000 | 29·43 |
| Elgin Chapter House, central pillar, red sandstone .. .. | .. | 40,000 | .. |
| Piers of St. Paul's Dome, London, squared limestone, Portland .. .. .. .. .. .. .. .. .. .. .. | .. | 39,000 | 19·35 |
| Piers of St. Peter's Dome, Rome, coursed rubble .. .. .. | .. | 33,000 | 16·35 |
| Keystone Neuilly Bridge, Paris, Sallancourt stone .. .. .. | 30,000 | 18,000 | .. |
| Party Wall, basilica of Constantine, Rome, coursed rubble faced with brick .. .. .. .. .. .. .. .. .. .. | .. | .. | 24·51 |
| Palace of the Chancellerie, Rome, columns of rez de Chaussées, squared stone .. .. .. .. .. .. .. .. .. .. | .. | .. | 34·11 |
| | Resistance of stone = 300 K. | | |

*General Principles of Wooden Roofs.*—Under the head of roofs are included all kinds of coverings of a permanent character to buildings; both the covering itself, which has to keep out the weather, and the framework which has to carry it.

If the covering is quite impervious, it may be nearly flat; but a horizontal beam, or framed girder, is not the most economical mode of spanning a large opening, especially in wood. As far as the framework is concerned, it is more economical to arrange it in one or more inclined planes or in a curve; and as few descriptions of covering are quite impervious or can be conveniently built in curves, the inclined planes are the most suitable mode of forming roofs in general. The inclination of the planes and the number of them must depend on the climate, the nature of the covering, and the circumstances of the case. With the same description of covering, supposing it to be only partially impervious, the inclination should vary according to the rainfall and snow of the locality; but this would be too unconstraining very generally, it may be said to vary according to latitude; but this would be too uncertain a guide for an architect. There must be a certain inclination for each country, at which a particular kind of covering will keep out the rain and snow. These inclinations for the English climate, for different kinds of coverings, will be given hereafter.

Garbet has stated a very proper general principle to be observed in all roof-frames, of whatever inclination, that the *numbers of orders of bearers should be as few as possible*. This will be best illustrated by describing the arrangement of ordinary roofs. When covered with slates or tiles, or any similar covering in small flat pieces, the bearers immediately under them must consist either of boards extending continuously underneath, or of battens placed horizontally at the interval of two courses of the slates or tiles. These again must be carried by beams called *rafters*, placed down the slope of the roof at right angles to the others. This arrangement Garbet would call two orders of bearers: it is the mode generally adopted in roofs not exceeding 20 ft. span: each pair of opposite rafters are generally tied together, either by a *tie-beam* at their feet or by a *collar-beam* about half-way up; from which this has got the name of the collar-beam roof.

When the span exceeds 20 ft., the bearers would become so large that it would be economical to introduce an additional order of bearers. The ordinary method is to support the *common rafters* by one or more beams extending horizontally beneath them, called *purlins*, which themselves are supported on other rafters below them, which latter being placed at considerable intervals, are much stronger, and are called the *principal rafters*. The common rafters rest against a horizontal beam standing on the foot of the principal rafters, and called a *pole-plate*, and abut against a horizontal *ridge-piece* at the top; thus they have little strain on them beyond the transverse strain between the purlins. The purlins are subject to a transverse strain between the principal rafters. The principal rafters are supported by a framework of which they themselves form a part, and which varies according to the span of the roof. This framework is called a *roof-truss* or a *trussed principal*, and forms the final and most important bearer of the roof. For spans between 20 and 30 ft., this truss generally consists of two *struts* supporting the principal rafters half-way down, and meeting in the centre, where their combined vertical force is suspended by a vertical rod or post called a *king-post*, to the vertex of the roof. The horizontal force at the foot of each principal rafter is carried by a tie-beam, which also supports the ceiling, if there is one, and is itself supported by the king-post.

When the span is above 30 ft., in order to provide intermediate points of support for the principal rafters, two vertical posts, in such case called *queen-posts*, are introduced each with its struts, the heads of the posts being connected by a horizontal beam, called a *straining-beam*, which carries the horizontal strains arising from them.

The general principle of such trusses is to carry the strains of the roofs in such a way as to relieve the walls from any but vertical strains.

Garbet would call the above arrangement one of *four* orders of bearers, namely:—1. Boards. 2. Common Rafters. 3. Purlins. 4. Principal Rafters. The usual interval for such "*trussed principals*" in ordinary roofs is 10 ft., and the interval of such purlins is about 6 ft.: with those fixed intervals this form of roof-frame is applicable to a considerable range of spans. It is evident, however, that as the span increases, it will at last be more economical to increase the interval of the principals, and to strengthen the purlins accordingly by framing or "trussing" them: and that for small spans it will be economical to combine the principal and common rafters in one, and to dispense with the purlins. The span at which it is desirable to introduce an additional order of bearers, in any such system of framework for constructions, is determined by considerations both of economy and stiffness; for, besides the calculations for the comparative cost with or without the additional bearer, it is necessary to consider the deflection; and as that varies directly as the cube of the length between the points of support, it may be desirable in some cases, where it is necessary to limit the absolute deflection, to introduce an additional order of bearers before the economical limit has been reached.

The examination of the strains exerted in a queen-post roof will sufficiently explain them for all this class of roofs. The *boards* or *battens* are subject to a transverse strain between the points of support afforded by the common rafters, which is made up of the weight of the roof covering and the allowance for pressure of wind (reduced to the vertical direction); they should never have a long bearing, as stiffness is very essential in the bearers of the roof-covering. Each *common rafter* is subject to a transverse strain between its point of support and to a longitudinal compression from the reaction from the opposite rafter, the force causing both these strains is that of the weight of roof-covering and boards, and pressure of wind bearing on the area supported by the rafter. The *purlins* and *pole-plates* and *ridge-pieces* are subject to transverse strains arising from the pressure of the common rafters they carry divided proportionally between them; the pole-plate also carries the longitudinal compressile pressure of the rafters, and transmits it to the principal rafters. The *principal rafters* are not generally subject to transverse strain, except from their own weight, but chiefly to longitudinal compression, because the purlins are generally placed immediately over the points of support of the rafter. Thus, at the junction of the lower strut with the rafter, the pressure of all that part of the purlin and its superincumbent weight that is carried at that point, is resolved into a compressile strain down the principal rafter, and another down the strut; and at the junction of the queen-post, principal rafter, and straining-beam, the pressure of that purlin, together with the vertical strain from the queen-post, are resolved into a compressile strain down the principal rafter, and another along the straining-beam: and at the upper strut a similar compressile strain results; and at the vertex, the pressure of the ridge-piece and vertical strain from the king-post are resolved into compressile strains down the principal rafters. Thus, the principal rafter is subject to accessions of compressile strains at these points from the vertex to the foot; and each part of it must be calculated accordingly to resist those strains. The *struts* are subject to compressile strains arising as above mentioned. The *king-post* and *queen-posts* are subject to tensile strains arising from the vertical components of the compressile strains.

*The tie-beam* is subject to the tensile strain which is the horizontal component of the compressile strain down the principal rafter; the vertical component of the same being carried by the walls. Tie-beams are generally made much larger than necessary to resist this strain only, even after allowing for the usual coefficient of safety, because they have generally to carry the transverse strain arising from the ceiling of the rooms below. The beams of that ceiling are generally fixed

to the tie-beams, each of which has therefore to carry all those beams and ceilings between two of the main trusses of the roof. For this reason the depth of the tie-beam is generally made much greater than its breadth. Each of these frames, or *trusses*, or *framed principals*, as they are called, are generally put together on the ground and hoisted into their places in one piece. The effect of putting the weight of the roof on this framework will be to deflect it a little out of its original form; some of the beams will become shortened and some lengthened; this should be taken into consideration in the design of the roof, as it not only throws the strains in different directions to those in the original form, but it alters the slope of the roof and may affect the junction of the eaves with the gutters.

The ends of the tie-beams generally rest on *wall-plates* or *templates*, and are sometimes *notched* on to them. The best position for the wall-plate is in the centre of the thickness of the wall, and the junction of the rafter and tie-beam should come immediately over it; and the most effectual mode of finishing the lower part of the roof is to allow the common rafter to project over the wall, and so carry the rain clear of the building. As the ends of the common rafters rest on the pole-plate, the whole pressure from the roof thus falls on the centre of the wall. When a roof is so finished, the lower part of it projecting over the wall is called the *eaves:* there is therefore an open space between every common rafter, which must be filled up to prevent the wind from entering the space between the roof and the ceiling. This is generally done with woodwork, which is called the *eaves' boarding*. In any method of finishing the eaves of a roof, the ends of the tie-beams should not be imbedded in masonry, or they will be liable to decay before the remainder of the roof. When there is a parapet or *blocking course* above the eaves of a roof, then either the parapet must rest upon projecting courses corbelled out from the outer face of the wall, or the wall-plate must be placed nearer the inner edge of the wall; in which latter case the pressure of the roof will not coincide with the axis of the wall. The wall-plate is not unfrequently placed close to the inner edge of the wall, and the junction of the tie-beam and rafter placed on the inner side of the edge; a practice which not only has the disadvantage of directing the line of pressure out of the axis, but subjects that short part of the tie-beam to transverse strain, thereby also causing a tendency to draw the wall-plate off the wall.

The ordinary method of framing these beams together, so as to send the strains in the directions required, will be considered presently; and Tredgold's rules for calculating their dimensions will be given hereafter.

*Flat roofs* are used in countries where there is little rainfall, as in the southern and eastern coasts of the Mediterranean, probably both from their usefulness and economy. The flat roof is not only the most simple mode of covering the house—a mere repetition of a floor—but adds another story and a garden to it. The following extract from a paper by Sir H. Jones on Maltese houses shows the mode of constructing a flat roof in that island: Beams of red pine from the Adriatic, about 10 by 12 in., are placed horizontally across the walls, at central intervals of about 4 ft. Sometimes a series of arched ribs of stone are built across from wall to wall instead of the beams. On these flat stones of the soft Maltese sandstone, about 4 ft. long, 10 or 12 in. wide, and 3 in. thick, are placed, butting close together without mortar; on these a concrete of red argillaceous earth and small stones, and called "*Forba*," is laid, with a slight slope on the upper surface to carry off the rain that falls: this forba is kept moist and beaten with rammers. When dry, there is spread over it a layer of cement ¾ in. thick, composed of four parts lime, three parts puzzolana, or of five parts lime and three parts pounded earthenware. This is spread in a liquid state, and then beaten with rammers and worked with trowels, and kept moist until it has set. The beating is done by women kneeling, with hand boards.

In countries where stone suitable for this purpose cannot be procured, timber is used instead, or a combination of wood beams and flat tiles, or wood beams and concrete of a quick-setting cement is used. Asphalte is sometimes substituted instead of cement for the exterior coating in this country when flat roofs are made; there is some danger in using it, on account of the expansion and contraction of the framework below. It is necessary in all flat roofs to make the framework very stiff—that is, to avoid any considerable amount of deflection, which would break the impervious coating of cement or asphalte; consequently, it would be desirable to introduce an additional order of bearers, or to provide in some other way for stiffening the structure at a smaller span than in an ordinary wooden floor. For the same object of stiffening the framework, it should be connected with the walls as firmly as practicable; the ends of the beams should be framed into the wall-plates or templates, which should rest on the wall as near the centre of its breadth as practicable. When a masonry parapet is made round the walls, great care should be taken in the construction of the open gutters at the sides to carry off the roof-water, and prevent it getting into the walls; frequent outlets through the parapet should be provided. Solid stone forms the most effectual gutter; and next to that, perhaps, a concrete of hydraulic cement.

*Gothic and Arched Roofs.*—In England roofs are generally made in one plane from the ridge to the eaves; but in France and some other countries, it is common to make them in two planes; this is partly for the architectural effect, but chiefly for the economy of gaining an additional story in the roof. The general method of arranging the roof is the same in almost all cases; there are the principal trusses at intervals, the purlins, the common rafters and boards; it is only the framing of the truss that varies. In the principal truss of the *Mansard* roof (as that of two planes is called, from the architect who first employed it extensively in Paris), besides the main rafters, which might be made to balance each other without ties, there are tie-beams from each angle to the next but one, and connected together at the crossing; these ties do not carry the whole horizontal strain of the roof, like that of the English truss, but leave a portion of it to be carried either by the walls, or by the strength of the bolt and beams at the crossing of two such ties.

In some of the old Gothic wooden roofs, the frame of the principal truss was made without any direct ties, chiefly for the sake of the effect when the timbers of the roof were visible, but also because the high pitch of the roof caused the horizontal strains to be less. The principal rafters

were generally supported by a collar-beam high up, and at one or two points lower down by vertical posts resting on the ends of horizontal pieces projecting from the point of support next below, the projecting points of junction of these vertical and horizontal pieces being connected by curved struts: the series of these curved pieces being carried from the walls on each side up to the collar-beam in the centre, they formed an imperfect tie to the roof—imperfect because it depended on so many joints, and because, if perfectly jointed, it resisted deflection by the strength of the joint, and not by the beam itself. The lowest of these curved pieces, being carried to a point considerably lower in the walls than the eaves, brought the general line of pressure of the roof to a lower point on the wall, and thus reduced the necessary thickness of the wall to meet it. Hampton Court Palace contains a good specimen of these roofs; those at the old palace at Eltham, and at Westminster Hall, are also remarkable examples.

When the span of a roof exceeds 50 ft., the queen-post roof-truss becomes heavy, and uses a large proportion of timber in the dead weight of the bearers: the polygonal or curved truss is one of the forms which has been proposed to avoid this ineffective use of timber in very large spans. In it a polygonal or curved rib of wood is formed, to which the tie-beam is suspended, and from which the purlins are supported: the curve of this rib should be such that a line of pressure will pass through it, thus putting it entirely in compression throughout its length; the tie-beam and suspension-bars will then be in tension. Dobson states that Philibert de Lorme was one of the first architects who proposed a polygonal rib of wood, which he constructed of two or more thicknesses of plank, the pieces of which were in equal lengths, and their ends abutted against each other; each thickness of plank thus forming a polygonal rib; the two thicknesses were bolted together.

*Walls of Framed Work.*—Walls of wooden buildings generally consist of vertical pieces, placed close enough together to support the boarding or plastering with which they are covered, and resting on a horizontal piece at bottom, commonly called a *ground-plate*, and connected at the top by a *wall-plate*. When the ground-plate is supported continuously by a wall, it only performs the part of an ordinary plate—that of distributing the pressures equally; and the uprights, or posts or *studs*, as they are sometimes called, are so many wooden columns, carrying each its proportion of the vertical pressure. No piece of quadrilateral framing can be put together so firmly as to resist completely some small distortion of shape from lateral pressure; therefore, it is most desirable in every wooden wall, as in every piece of framework, to have some inclined pieces framed into the structure, by which the pressures can be resolvable into triangles. These inclined pieces, which are called *struts* or *braces*, are sometimes only battens fastened across the studs. The corner-posts are generally larger, as they have to withstand a double lateral pressure. It would make a stiffer, though a more expensive wall, if the studs were placed farther apart, and, consequently, made of large cross-section, and an intermediate order of bearers for the boards was introduced. In America a wall is sometimes made entirely of boards in two or more thicknesses, placed at right angles or diagonally to each other. When a wooden wall has to span an opening, as is frequently the case in the interiors of houses, in partition walls covered with lath and plaster, it becomes a very deep-framed girder, and should be framed on the principle of the queen-post truss, in which the braces would represent the principal rafters, and the top plate would represent the straining-beam, and the bottom plate would be the tie-beam, which should be supported from the top plate and braces by the vertical studs; in such a framework the studs below the braces would be in tension; those above the braces in compression. The bottom plate might in such case support part of the weight of a floor or ceiling. In arranging the openings for doors and windows in wooden walls, great consideration should be paid to the position of the braces; the studs on each side of the opening should be made stronger than ordinary studs, in order to form the framework of the door or window; and with a careful arrangement of the braces in connection with these frames, these openings may be made to add to the stability of the wall.

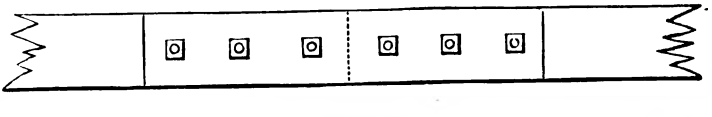
*Scarfs.*—In all scarfs and joints in woodwork, it is an important principle that the bearing parts should have as large a surface as possible, in order to save the fibres from injury. For the same reason, timbers in framework should be cut as little as possible. Also, that the inevitable expansion and contraction of the wood should be borne in mind in the form of the joint.

The following notes on scarfs and joints are extracted from Tredgold's Carpentry:—

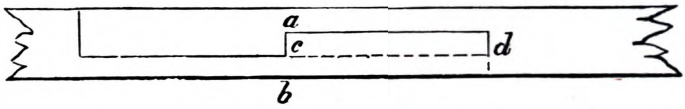
1. *Longitudinal scarf to resist tension only*, such as for some tie-beams, king-posts, and so on.

*Fish-joint*, Fig. 2058.—In this the two pieces of timber abut on each other, end to end, and an iron or wooden plate is fastened on each side by bolts passing through the beams; the tensile strain is thus passed through the bolts to the fibres of the timbers. The shrinkage of the timbers loosens this joint, and the pressure of the bolts injures the fibre; the total area of bolt-sections should be at least equal to $\frac{2}{10}$ the area of the section of beam.

2058.



2059.




*Indented Scarf*, Fig. 2059.—To determine the depths of indents and length of scarf, the tensile strength of $b\,c$ should be equal to the compressile strength of $a\,c$ and to the shearing strength of $c\,d$. Therefore, when the compressile and tensile resistances of the wood are equal, $b\,c$ should be $\frac{1}{4}$ the depth of the whole beam.

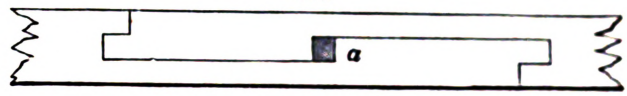
In fir and other straight-grained wood, $cd = 16$ to $20\ cb$.
In oak, ash, elm, and such woods, $cd = 8$ to $10\ cb$.
In fir, and so on, a scarf with bolts only, the whole length of scarf = 6 times breadth of beam.
In oak, " " " " " = 3 " "
In fir, a scarf with bolts and indents, the whole length of scarf = 4 times depth of beam.
In oak, " " " " " = 2 " "

2. *Longitudinal joint to resist compression:* as for pillars, struts, and so on.

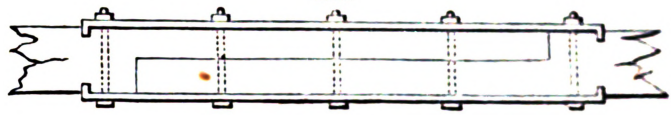
*Fish-joint*, Fig. 2060.—If four fishing-pieces are used, one on each side of the joint, and a piece of hard timber is inserted between the ends of the pieces, to distribute the pressure equally, an effective joint can be made without injuring the fibres.

*Indented Scarf*, Fig. 2061.—Similar calculations can be made for this, as for the joint, to resist tension: a key or double wedge of hard wood is inserted at *a* to ensure a fair bearing; they should not be driven too tight, or the fibres of the beam may be injured. No bolts or plates are required for it; but a tongue or mortice and tenon at each end is necessary, to prevent side shifting, as at *c*, Fig. 2059.

2060.

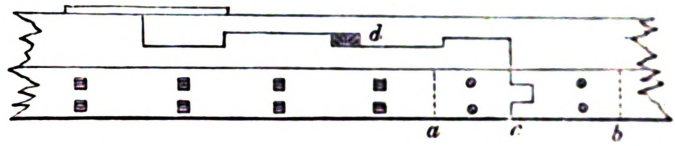



2061.



*Plain Scarf.*—This joint is to be recommended, as it does little injury to the fibres, and the bearing surfaces are large and perpendicular to the strains; but it requires bolts and plates, Fig. 2061.

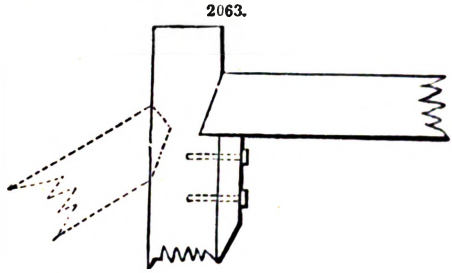
2062.



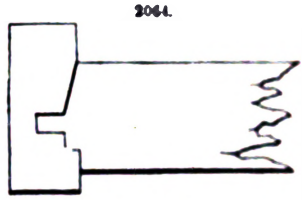

3. *Longitudinal joint to resist transverse strain*, as in some tie-beams and girders.—This joint is recommended. The depths of indents and lengths of scarfs may be calculated as for tensile strain. It is necessary to have a plate over the joint on the upper and lower sides, as at *a b*, and bolts through the beams; at *d* are the hard-wood wedges, Fig. 2062.

*Straining-beam.*—A horizontal beam may be connected with and supported by a vertical beam (as in the case of straining-beams in a roof) in the manner shown, Fig. 2063.

2063.



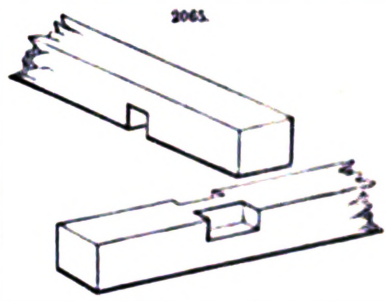
2064.



*Joints.*—4. *Transverse joints, horizontal*, as in joists, purlins, and all such beams resting on or framed into others, and subject to transverse strain.

*Framed Joint.*—This is applicable to horizontal beams, which are to be framed in between two others, in order to avoid increasing the total depth of the bearers, such as the bridging of joints in a framed floor. A projection is formed on one beam, called the *tenon*, and a hole to receive it cut in the other, called a *mortice*. The mortice should be cut in the neutral part of the beam—that is to say, in the middle of the depth. The tenon should be as near the bottom as practicable of the other beam. The form in Fig. 2064 is recommended for combining these objects with other requirements in the framework. The tenon is $\frac{1}{3}$ the depth of the beam in thickness, and at $\frac{1}{3}$ the depth from the lower side. The object of the bevelled part above, and of the shoulder below, is to strengthen the bearing surface of the tenon.

2065.



It is almost impossible to make a tenon fit so well into a mortice that it will replace the original wood in the hole: and even if it did at first, the shrinking of the wood would soon loosen it. Therefore, double tenons are not recommended in carpentry, on account of the difficulty of making both of them to bear equally.

*Notching*, Fig. 2065.—When the other arrangements of the framing admit of it, it is always better to connect two horizontal beams together, which are subject to transverse strain, by *notching*—that is, by resting one across the other, and cutting a kind of tenon in the lower one, and a corresponding

mortice in the upper one. There is both a practical advantage in this, in being able to use long timbers, and a theoretical one, in getting a better bearing, and in having the upper beams virtually fixed at each end, instead of merely supported, as in the former method.

*Cross-framing*, Figs. 2066, 2067, as in wall-plates and such beams, which have to be connected together and are not subject to transverse strain.

The beams are *halved* into each other, as it is called, half the thickness of the beam being cut out of each. Sometimes the form of this halving is *dovetailed*, as in Fig. 2068, which is objectionable, because the shrinking of the timber causes the joint to become loose; for this reason no *dovetailed* joints are to be recommended in carpentry. The better form for the halving is shown in Figs. 2066, 2067.

5. *Transverse joints, perpendicular*, Figs. 2069 to 2071; such as posts or studs into plates.—The object of every system of joints is to reduce all the pressures into the direction of the axes of the pieces.

The ordinary mode of connecting two beams, the one perpendicular and the other horizontal, is by cutting two shoulders in the end of the perpendicular piece, leaving a *tenon* or tongue between them, which fits into a corresponding *mortice* or hole cut in the horizontal pier. As the only object in the tenon and mortice is to prevent lateral motion, Tredgold recommends a short tenon having a thickness of about *one-quarter* that of the timber.

It is evidently of great importance that the tenon and mortice should be cut square and accurately; on account of the difficulty of ensuring this, Tredgold recommends an angular-shaped or a curved joint, as shown in Figs. 2070, 2071.

6. *Inclined joints*, Figs. 2072 to 2074; such as principal rafters with tie-beams.—The resistance of a joint is always most effectual where the abutment one piece rests against is perpendicular to the strain down that piece. Thus, in the figure, if the strain down the rafter is in the direction $c\,b\,e$, and $b\,a$ is one of the abutting surfaces, then, if $a\,c$ be drawn perpendicular to $b\,a$, and $b\,d$, the other abutting surface, be made parallel to $a\,c$, then in the triangle of forces $a\,b\,c$, if $b\,c$ represent the whole strain, $a\,c$ will represent the strain on $b\,a$, and $b\,a$ will represent the strain on $b\,d$: thus the two components of the whole strain will be perpendicular to the two abutting surfaces. Tredgold recommends that $b\,d$ should be rather more than half the depth of the rafter. There should be a tenon at the under-side of the rafter, and a mortice in the tie-beam, to prevent the beams slipping over each other; the thickness of the tenon should be about $\frac{1}{3}$ that of the beam. As the shrinking of the wood, which is sure to occur after the framework is up, will have the effect of lowering the slope of the rafters, and thus bring a greater pressure about the point $a$ of the joint, that part of the joint should be left a little open, as shown in the figure, in the original construction of it.

Tredgold recommends either of the accompanying forms for this joint, in which the tenon is made on the tie-beam, and the mortice on the rafter; it has the advantage of showing the whole of the workmanship of the joint more completely to view than the other method.

7. *King and Queen Posts*, Figs. 2075, 2076.—The upper end of the principal rafters may be framed into the king-posts in a similar manner to the lower end into the tie-beam. But in this case the joint, when originally made, should be left slightly open at $a$, as the effect of a settlement from shrinking will be to bring a greater pressure on that part. Or, the upper end of the king-post may be enlarged and cut with a shoulder at right angles to the direction of the rafter. In both these cases there should be a small tenon and mortice to prevent the beams slipping over each other sideways. The lower ends of the struts may be connected with the king-post by either of the above methods: if the king-post is in two pieces, a very good joint may be formed with the principal rafters, by letting them abut against each other between the two parts of the post, as in Fig. 2075, the two parts being bolted together above and below the junction.

The *struts and principal rafters* may be connected by a joint similar in principle to that of the rafter and tie-beam. The *purlins*, *pole-plates*, and *ridge-pieces*, are generally notched into their respective beams.

The following practical rules by Tredgold for determining the size of the beams in wooden roofs, of the description of framework before mentioned, are based on the theoretical calculations for the resistance of beams to deflection. He apparently considered that the amount of deflection in a framework is of as much importance as the absolute strength; then assuming that for security the deflection of any beam ought to vary inversely as its length, and starting with some fixed arbitrary deflection for a given beam, and assuming that the arrangement and intervals of the beams and the loads upon them are constant, he obtained from these data and his own judgment a set of constant coefficients for the different beams for fir wood and oak wood, in terms of their dimensions, span of roof, and so on. These rules generally give large dimensions compared with those for absolute strength.

*Principal rafters*, assumed central interval = 10 ft.

$$d = 0{\cdot}96\,\frac{l^2\,\mathrm{L}}{b^3}$$

$b\,d$ = breadth and depth of beam in inches,
$l$ = length of beam in feet,
L = span of roof in feet,

which is virtually the theoretical equation for a long beam subject to compression in the direction of its length.

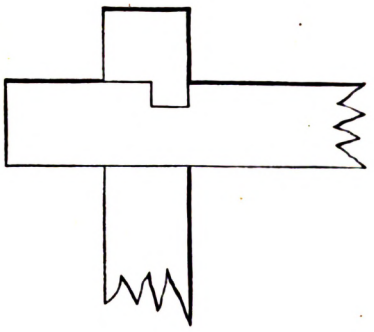
*Straining-beam.*—$d = 0{\cdot}9\,\sqrt{l\sqrt{\mathrm{L}}}$, which is also the same theoretical equation, $b$ being taken constantly as $= 0{\cdot}7\,d$, which is an arbitrary assumption.

*Struts.*—$d = 0{\cdot}8\,\sqrt{l\sqrt{\mathrm{L}}}$, $b$ being taken constantly $= 0{\cdot}6\,d$.

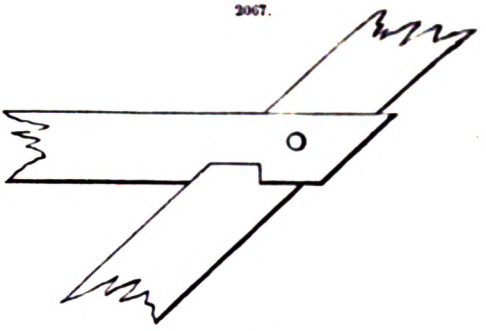
*King-posts.*—$b\,d = 0{\cdot}12\,l\,\mathrm{L}$.

This rule for a beam under direct tension, is evidently based on the same law that the elonga-

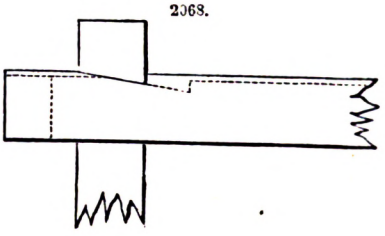
2066.



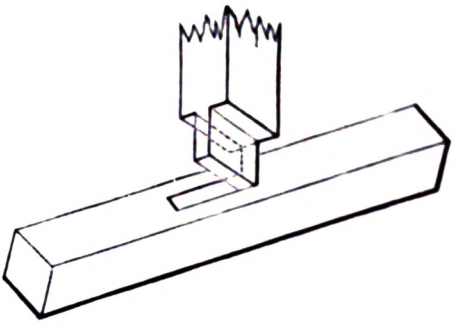
2067.



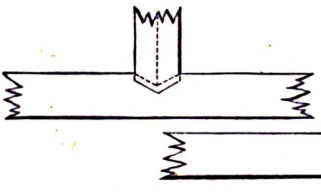
2068.



2069.



2070.



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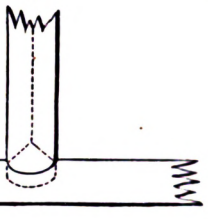

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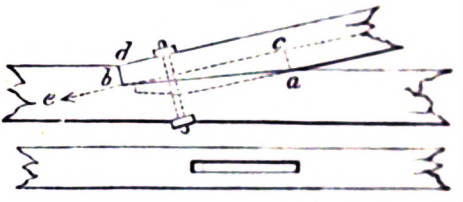


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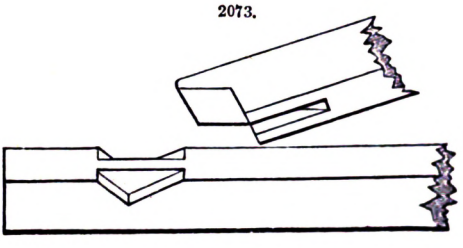

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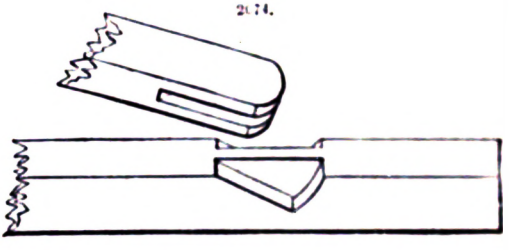

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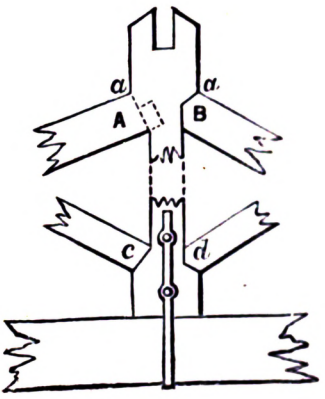


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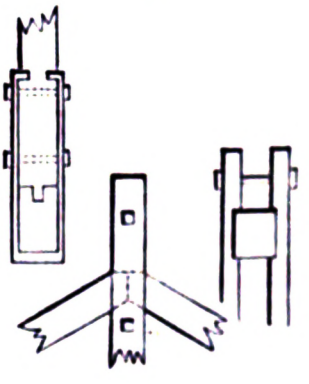


tion should be inversely as the length of beam: and this gives of course much larger dimensions than are required for absolute strength.

*Queen-posts.*—$b\ d = 0{\cdot}27\ l\ L_1$, $L_1$ = length in feet of that part of tie-beam carried by the queen-post.

*Tie-beams.*—$d = 1{\cdot}47\ \frac{l_1}{\sqrt[3]{b}}$; $l_1$ = length in feet of longest part of tie-beam unsupported.

This is virtually the same as the theoretical equation for the deflection of a beam subject to transverse strain; in this case, apparently, the tensile strain on the tie-beam is expected to counterbalance to some extent the deflection caused by the transverse strain.

*Common rafters.*—$d = 0{\cdot}7\ \frac{l_{11}}{\sqrt[3]{b}}$; $l_{11}$ = length in feet of bearing between one purlin and another.

Common rafters should be at least 2 in. thick to hold the nails of the laths or boards.

*Purlins.*—$d = \sqrt[4]{D\ l^3_{111}}$; D = distance in feet of purlins from each other.

$b$ is assumed constantly $= 0{\cdot}6\,d$. $l_{111}$ = length of bearing of purlin in feet.

These two last are virtually the same as the ordinary theoretical equations for deflection of beams subject to transverse strain.

*Roof Coverings.*—The object of all roof coverings is to keep out the wind, rain, and snow, and to keep an even temperature inside as far as practicable.

A roof covering of small pieces is generally heavier, more difficult to keep dry, and requires a steeper slope than one of large pieces, but the material itself is cheaper.

In a roof covering, the crown or meeting of the planes at the top is technically called the *Ridge*; the meeting of two planes forming a salient angle down the slope of the roof, as frequently occurs at the end of a building, is called a *hip*, and such a roof is said to be *hipped*. The meeting of two planes forming a re-entering angle down the slope of the roof, as occurs at the junction of one roof at right angles to another, is called a *valley*; the lower edge of the roof, where it meets the wall, is called the *eaves*.

*Slates* form the most effective and durable roof covering of any stones or tiles. They are used all over England from the facility with which they are obtained. The strata of roofing slate are found in all the Silurian series of rocks to which they belong. They are quarried by blasting, and are split and cut into sizes at the quarry. As it is convenient to have slates all one size in one roof, they are cut to fixed dimensions according to the size of the blocks obtained from the quarry; consequently the larger slates are more expensive. The best slate for roofing is of a light sky-blue colour, and gives a clear bell-like sound on being struck; dark blue or blackish slate absorbs moisture and decays more rapidly.

The following, taken from Hurst's Tables for Engineers, are the sizes and the technical names of the slates in ordinary use for roofing in England:—

| Name. | Size. | Gauge. | No. of Squares covered by 1200. | No. required to cover 1 Square. | Nails a Square. | |
|---|---|---|---|---|---|---|
| | | | | | Iron, No. | Copper. |
| | in. in. | in. | | | | lbs. |
| Doubles .. .. .. | 12 × 8 | 4½ | 2·8 | 430 | 430 | 5 |
| „ .. .. .. | 13 × 6 | 5 | 2·5 | 480 | 480 | 5½ |
| Ladies .. .. .. | 14 × 12 | 5½ | 5·0 | 240 | 280 | 3½ |
| „ .. .. .. | 15 × 8 | 6 | 4·0 | 300 | 300 | 3½ |
| Viscountesses .. .. | 18 × 10 | 7½ | 6·0 | 200 | 200 | 2¾ |
| Countesses .. .. | 20 × 10 | 8½ | 7·0 | 171 | 342 | 4 |
| Marchionesses .. .. | 22 × 12 | 9½ | 9·4 | 130 | 260 | 3¼ |
| Duchesses .. .. | 24 × 12 | 10½ | 10 | 125 | 250 | 3 |
| | | | By 1 ton. | | | |
| Imperial .. .. .. | 30 × 24 | 13½ | 2·5 | 48 | 96 | 3 |
| Rags .. .. .. .. | 36 × 24 | 16½ | 2·2 | 40 | 80 | 3 |
| Queens .. .. .. | 36 × 24 | 16½ | 2·5 | 40 | 80 | 2½ |

The slating of a roof begins from the eaves. The slates are shaped and trimmed on the ground, and two holes are punched through them near the upper end for the nails to fasten them to the boards or battens. Slates may be laid either on boards or battens; these are generally at right angles to the last course of bearers, and therefore generally horizontal; there is less cutting to waste of them when they are laid horizontally; the boards or battens are seldom less than 1 in. thick, on account of the slating nails which have to be driven into them; battens should be at the utmost at the interval apart of two consecutive courses of slates. Boards are generally used for important buildings, they are stiffer, and keep out the wet and the heat better than battens. The first course of slates at the eaves is little more than half the width of the other courses; it is called the doubling eaves' course, and the next course covers it completely, a special batten being laid under it to give it the same slope as the others: the second course is called the covering eaves' course. At the ridge another half-course is laid over the last course. Slating should have a bond or overlap of at least 2½ in., that is, the third course should overlap the first course by 2½ in., and the fourth should overlap the second by the same. Hence, if the overlap be deducted from the length of the slate, half the remainder will give what is called the margin or *gauge* of the slating. At the hips and valleys the slates are cut to fit the required angles.

For the nails for fastening slates *copper* is the best material, and is generally used in important buildings. Zinc and iron nails are sometimes used, but the former are not strong enough, and the

latter are soon destroyed by rust; the partial protection which is sometimes given them by dipping them in boiled linseed oil, does not preserve them much longer, and a coating of tin is an uncertain protection. Slates for ridges and hips are sometimes cut out of thicker pieces than ordinary; they are generally in two pieces, and are joined together on the roof with slate mastic, and form very effective and durable coverings.

Large slabs of slate are frequently used for special roofs, and for cisterns and other similar purposes. They are expensive and require great care in fixing, especially in forming the water-tight joints.

*Tiles* are now made in England in great variety of forms. They are made in almost all districts where clay for brickmaking is found; but they should be made of a more plastic clay than that for ordinary bricks, otherwise they are liable to lose their shape in the burning. The preservation of the shape is indeed the only limit to the size of tiles; the larger the tile the lighter the roof covering; large well-burnt tiles would be almost as effective, light, and durable a covering as slates, though requiring a steeper slope: and if a cheap method of glazing them should be discovered they will probably supersede slates to a great extent.

*Plain tiles* are the oldest and commonest form of tile in England. They are flat and about 10 in. by 6 in., and ½ in. thick, and weigh 2·13 lbs.; they are generally laid on *laths* of fir about 1¼ in. wide and ⅜ in. thick, nailed to the common rafters and therefore horizontal: two holes are formed in the tile, near the upper edge, through which they are fastened with wooden pins to the laths. The overlap of one course over the next is generally from 6 in. to 8 in.; rows of laths are fixed at intervals to give the required overlap, between each of which an intermediate row is placed: the tiles are bedded in mortar, which should of course be hydraulic: the tiles in one course are laid with their sides touching, the next course is laid with these joints occurring over the spaces between the joints of the course below.

There are flat tiles used in France 12 in. by 9½ in.

A square of plain tiling requires 700 plain tiles; 1 bundle of laths, or 500 ft. lineal; 600 nails, 4 lbs. to the 1000; 4 cub. ft. of mortar; and 1 peck of wooden pins, or ¼ bushel.

*Pantiles* were introduced into England from Holland; they are curved in transverse section, with a kind of lip on one side to cover the joint with the next tile in the same course. They measure about 14 in. long and 7 in. to 9½ in. across the chord of the curved part, and about ⅜ in. thick, and weigh 5½ lbs. They are made with a tongue projecting from the centre of the upper edge to the rear; by which they are hooked on to the laths. The overlap of one course over the next is from 3 in. to 4 in., consequently they form a much lighter covering than plain tiles. The laths are from 10 ft. to 12 ft. long, 1½ in. wide, and 1 in. thick. The tiles should be pointed on the inside of the horizontal and vertical line joints with "hair mortar," that is, common mortar with a small portion of ox hair mixed with it. With pantiles it is usual to employ special tiles to cover the ridges, hips, and valleys.

The ridge and hip tiles are curved, and are about 12 in. long and 9½ in. across the chord; they are laid in mortar without any overlap, and are fastened with nails or hooks. *Valley tiles* are curved and triangular-shaped, and are about 10½ in. by 12 in.; they overlap, are laid in mortar, and fastened with wooden pins like plain tiles.

A square of pantiling requires 180 pantiles; 1 bundle of 10 ft. laths, or 120 ft. lineal; 150 nails, 10 lbs. to the 1000; and 6 cub. ft. of hair mortar.

*Italian Tiles.*—The system of roof covering that has been in use all over the Mediterranean from the earliest known periods, has been that of the ridge and furrow tiling; one set of curved or channelled tiles being laid with the concave side uppermost, to form a series of channels down the slope, and another set laid with the curved side uppermost, covering the joints of the former, and forming a series of ridges between the channels. This system is not so effective as plain tiles in countries exposed to heavy winds and snow, because the number of irregularities in the surface of the roof afford so many points for the wind to act on and for the snow to accumulate in. Sometimes the channel and ridge tiles are both the same, or about the same shape, as is the case in Chinese roof covering. M. Renaud mentions the following usual form now in use in Italy:—The channel tiles (*tegoli*) are flat, and about 16 in. long, 10 in. wide at the lower end, and 13 in. at the upper, with a ledge or rim down each side; the ridge tiles (*canali*) are curved, and about the same length, and 6½ in. wide at the upper end and 9 in. at the lower; the overlap is about 3 in. On the common rafters of the roof (which are at about 1 ft. central interval) are laid common flat tiles, and on these the ridge and furrow tiles are laid. The proper slope for them is from 15° to 27°, and the weight of a square of 100 sq. ft. is 1800 lbs.

*A triple pantile* (as it is called) is made by Browne, of Bridgewater; it is 16½ in. by 14 in., and 1 in. thick, and weighs 7¾ lbs.

*Thatching* is a name given to a kind of covering over roofs: it is generally made of wheaten straw, laid on lathing and rafters, which may be of the same strength and placed the same distance apart as for a common slated roof; but in country places, where thatching is mostly used, the rafters are generally formed of the branches of trees of from 3 in. to 6 in. in diameter; the slighter they are the better, provided they are sufficiently strong, as the lighter the roof is the less strain there is on the walls: of course, if the rafters are stout, they should be placed farther apart than slight rafters; and if the rafters are far apart, the lathing must be stronger, otherwise the thatching will bag, or lay in hollows between the rafters.

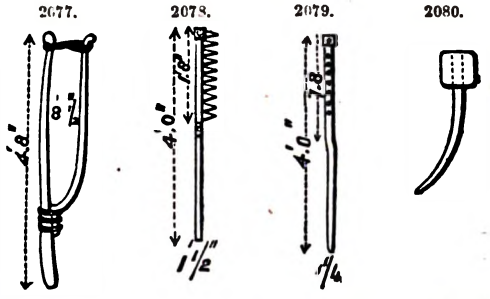
The straw is laid on the lathing in small bundles called hellams, until it attains a thickness of from 12 in. to 16 in.; it is fastened to the rafters with young twigs and rope-yarn.

A good pitch for a thatched roof is 45°, or, as it is technically called, a true pitch: if the pitch is made less, the rain will not run off freely; and if a greater pitch than 45° is used, the straw is found to slip down from its fastenings.

*The Thatcher's Tools are:—*

*A common stable fork.*—This tool is used to toss the straw up together when it is wetted, preparatory to its being made into bundles for use.

*A thatcher's fork*, Fig. 2077.—This is a branch of some tough kind of wood, cut with two smaller branches proceeding from it, so as to form a fork, as shown in the diagram; the joint of the two branches is generally strengthened by a small cord, to keep it from slipping when it is used. A small cord is fastened by one end into one of the ends of the fork, and a loop is spliced on the other end of the cord; this loop is made to pass over the other end of the fork, and to fit into a notch cut to receive it, as shown in Fig. 2077.




This tool is used to carry the straw from the heap, where it has been wetted and prepared, up to the thatcher on the roof, where it is to be used.

*A thatcher's rake*, Figs. 2078 to 2080.—The handle should be of ash or some tough wood, made not round but square, so that it may be grasped firmly without fear of its slipping round in the hand: the arrises may be slightly rounded off, so as not to hurt the hand. It will be seen by referring to Fig. 2079 that a crook is formed in the handle; the reason for this will be explained when we come to speak of the manner of using the different tools.

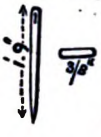
The use of this tool is, after the straw is laid, to comb it down straight and smooth.

*A thatcher's knife, or eaves' knife.*—This tool is similar in shape and make to the reap-hook, except that it is larger, and not curved so quickly.

The use of this tool is to cut and trim the straw to a straight line at the eaves of the roof.

The thatcher also requires a knife shaped something like a bill-hook, to point the twigs used for securing the straw.

A half-glove or mitten, of stout leather, to protect the hands when driving in the smaller twigs, called spars.




A long flat needle, Figs. 2081, 2082.

A pair of leather gaiters, to come up above the knees, to protect his knees and shins when kneeling on the rafters.

A sharp grit-stone to sharpen the knives.

*The Timbering and Lathing necessary for a Thatched Roof.*—As before stated, the rafters for a thatched roof may be of round timber, such as the branches of trees, *and young trees*, of from 3 in. to 6 in. in diameter, placed not more than 14 in. from centre to centre, but sometimes the rafters are of sawn timber: in that case they should be cut about the same scantling as for a slated roof, not as for a tiled roof.

The lathing in a thatched roof being very liable to rot, it should be split out of heart of oak, or some other equally durable wood: the laths are about 1¼ in. wide, and ¼ in. to ⅜ in. thick, and are nailed on the rafters about 8 in. apart in a horizontal direction, just the same as for a tiled or slated roof.

If the laths are placed farther apart than 8 in., the straw is apt to bag or sink down between them; the rain lodges in the hollows, and of course soon rots the straw.

An eaves' board about 7 in. wide is required to start the first part of each course of thatching upon.

*A description of the manner of executing a Thatched Roof.*—The rafter and eaves' board being fixed, and the lathing nailed on in rows at the prescribed distance apart before mentioned,—

As much straw is taken as it is thought will be required for the whole roof, which may be got at by estimating a square to take from 3¼ to 3¾ cwts. of wheaten straw: care should be taken to keep the fibres or stalks as parallel to each other as possible. As each truss of straw is opened, it is spread out and wetted, using about 3 or 4 gallons of water to each truss. The straw is then tossed over and mixed together in one great heap with the stable fork, so that every part may get an equal portion of the water. If the weather is fine and dry, the straw may be used directly; but if the weather is damp or rainy, the straw should be allowed to lay for a day or so to drain, and be once more turned over.

The reason for wetting the straw is to make it lay close, and to enable the thatcher's labourer more easily to draw the stalks out parallel.

The thatcher and his labourer being now ready to commence, the labourer spreads as much of the straw on the floor as will make a bundle 12 in. wide and 4 in. thick; the labourer then stooping down, with his left hand draws the straw, little by little, to his feet, and while doing so, with his right hand draws out any loose straws that may be lying crosswise: by this means he gets a compact bundle of straw from 3 ft. to 4 ft. long, according to the goodness of the straw, and all the stalks are parallel. This bundle is called a "hellam." The labourer having placed four or six hellams crosswise in his thatching fork, he carries it on his shoulder up to the thatcher on the roof, in the same manner as a bricklayer's labourer carries a hod of mortar: the fork is secured on the roof by a small peg and a piece of string.

The thatching is now laid in courses 3·0 wide, beginning at the right end of the roof, so that the thatcher works from right to left. The courses are laid parallel with the rafters, and not parallel with the lathing (as is the case in slating and tiling). Care must be taken at starting the eaves to have a good firm body of thatch, letting the straw hang over, to be afterwards trimmed with the eaves' knife to a straight and good-looking edge. A row of three hellams is placed on each succeeding lath in the course, and each row of hellams is secured to the rafters with a young tough twig, called a ledger; it is about 4 ft. long and 1 in. in diameter: each row of hellams is also secured to the row underneath it with three split twigs, called spars: the spars are about 2 ft. long, and eight can be split out of a branch 2 in. in diameter; they are pointed at both ends, and are then doubled in two, and the thatcher gives them two twists round in his hand, in the same

manner as a rope is twisted: this gives the spar a splintery surface, and enables it to hold on when driven into the straw.

The thatcher has a leather glove on his right hand: and keeping his hand flat or open, he gives the spar two or three smart blows, sufficient to drive it into the straw, and the leather serves as a protection to the hand. The spars must be soaked in water for some hours before they are used, in order that they should not break in the doubling up.

The *ledger* is a tough twig, about 4·0 long and 1 in. thick, as before described: one end is pointed, and driven or rather pushed 6 in. under the outside rafter of the course: it is then brought over the top of two rafters, and over the top of the hellams, and then secured to the inside rafter of the course with about 8 ft. of rope-yarn, by means of the long flat needle, thus holding down the row of hellams, and preventing them from slipping off the roof. In speaking of the outside and inside rafter of a course, it is meant by the outside rafter, the rafter that is farthest from the thatcher; and by the inside rafter the one that is nearest to him; and thus the inside rafter of one course becomes the outside rafter of the next course.

The thatcher gives each course, as it is laid, a combing down with his rake, to get out the loose straws: he then takes a bucket of water, and throws it right down the course, and gives the straw a good beating with the back of his rake, to break any stubborn straws and to make it all lay close: he then finally gives it another combing, and after that smooths it down with the back or flat side of his rake, and it is finished.

It will be seen by referring to Figs. 2078 and 2080, that a crook is formed in the handle of the rake. The reason for thus crooking the handle is to keep the thatcher's hand from contact with the straw, and thereby save his knuckles.

The ridge and hips are managed thus:—The thatcher, in doing one side of his roof, takes care to leave a good length of screw hanging over and past the ridge. As he finishes the top of each course on the other side of the roof, he bends down the tops of the first side, and covers them over with the last row of hellams on the last side, bending these last in their turn down over the other side of the roof.

The ridge is then secured on each side with three rows of bands or spars, placed end to end, and each spar is secured with three other spars to thatch.

In the case of the hips, there are no bands of spars, but single spars, 12 in. apart, are bent crosswise over the hip, and secured with three other spars, as before. The eaves are also secured with two rows or bands of spars.

Wheaten straw thatching, done as here described, will last in our climate from fifteen to twenty years. Oat straw, about eight years.

*Shingles*, or wooden slates, are made from hard wood, either of oak, larch, or cedar, or any material that will split easily. Their dimensions are usually 6 in. wide by 12 or 18 in. long, and about $\frac{1}{4}$ in. thick. They are laid in horizontal courses of 4 or 5 in. gauge, nailed upon boards, the joints broken, commencing with the eaves' course. The ridge is secured by what is called a ridge-board, or a triangle of inch stuff of 6 or 8 in. each side. In America, where this roof is common, the mechanics have a special tool for shingling, called a shingle-axe, with a hammer at the back.

*Metal Coverings.—Metal coverings* are generally laid in large sheets or plates, and as they are for the most part composed of materials of great tenacity, one of the intermediate orders of bearers can generally be dispensed with, and the sheets of metal can be laid on the rafters or purlins. Metal coverings should be fastened in such a manner as to admit of expansion and contraction, and therefore not with nails as a general rule; also, because the nail-holes, if exposed, soon enlarge with rust and form leaks.

*Iron.—Cast-iron plates* are seldom used, except when the roof consists of a reservoir or tank, in which case it is frequently made of cast-iron plates bolted together by means of flanges. Cast iron is frequently employed in roofing, for eaves' gutters, and rain-water pipes, and is one of the most effective materials that can be used for these purposes. Both gutters and pipes may be made as thin as they can be efficiently cast; the gutters may be of any cross-section required to correspond with the other mouldings; for an ordinary roof they should not be less than 5 in. deep in this climate. With that depth they may be laid nearly horizontal, as it is an advantage to have some water always in the gutter. The lengths or pieces should be connected by flanges and bolts, to allow of the introduction of fresh packing. The connection of the gutter with the wall should be very firm, and such as to allow for its expansion and contraction. With such a gutter a *down-pipe* or means of escape for the rain should be provided at about every 50 ft. lineal of gutter; this should not be less than 4 in. in internal diameter, and should have a larger head with a grating over it to prevent leaves or other matter getting into it. *Wrought-iron plates* are used both flat and corrugated. With flat plates the mode of forming the longitudinal joints (down the slope) mentioned by Renaud is the most effective, namely, by bending the two edges of the adjacent plates over a roll of wood extending down the roof, so as to avoid nailing. *Corrugated wrought-iron plates* have been much used of late years in this country. They are made in sheets about 12 ft. long and 6 ft. wide, and in thicknesses from about No. 25 to No. 15 of the Birmingham wire-gauge (that is, from about $\frac{1}{20}$ to $\frac{1}{16}$); the corrugations are from 2 to 5 in across. It is only necessary to support medium-sized corrugated iron at intervals of about 6 ft., hence the framework of the roof can be simplified; the corrugations being placed so as to form ridges and furrows nearly extending down the slope of the roof, the overlap of the sheets at the sides forms of itself a nearly water-tight joint; it is necessary, however, to fasten the sheets with nails along the top and bottom of each sheet to horizontal purlins or battens, in order to prevent them being lifted by the wind. These nail-holes are sources of decay and leakage.

No thin sheets of wrought iron will last many years without some artificial coating, and no artificial coating at present in use will effectually prevent oxidation, without frequent renewal. With thick plates not liable to any disturbing causes, the coating of oxide forms an effective

covering in itself, for it will not penetrate far into the iron and resists further change; but the liability to decay from rust of thin plates, especially when exposed to the action of any acid, has checked the application of wrought iron as a roof covering. A coating of zinc is applied to such plates for this object, and preserves them for several years, but wherever the coating is broken through, both the zinc and the iron decay rapidly; for this reason no holes or cuttings should be made after the zinc has been applied, and a coating of paint is frequently desirable in addition to the zinc.

*Lead* is the most durable covering for roofs of all the metals. Its malleability requires that it should be supported on boards, and as it must be of considerable thickness to retain its shape, it forms a heavy covering. There are two kinds of lead used in roofing, *cast* and *milled*. The former is the harder of the two, and is preferred for flats, cisterns, gutters, and tanks; the latter being more malleable is preferred for hips, ridges, and flashings. Both kinds are made in sheets about 6 ft. wide, and the cast from 16 to 18 ft. long, and the milled from 18 to 25 ft. long, and it is generally designated by the weight per square foot: that for flashings being not less than 5 lbs.; for hips, ridges, and valleys not less than 6 lbs.; for gutters, flats, and cisterns, not less than 7 lbs. a sq. ft. 5 lb. lead is about $\frac{1}{16}$ in. thick, and 7 lb. about $\frac{1}{8}$.

As the expansion of lead is considerable with increase of temperature, the joints must not be fastened together by *solder* or by any other means: when a joint is required to be in the direction of the slope, it is made by a *roll* of wood as above mentioned for iron plates; when the joint is across the slope, it is made by what is called a *drip*, which is a small vertical fall arranged in the boarding over which the two edges of the lead sheets overlap. Lead on *flats*, that is roofs nearly horizontal, should be laid in widths not greater than half the width of the sheet; on gutters and flashings it should be in lengths not greater than half the length of the sheet. Gutters and flats should have an inclination of at least $\frac{1}{4}$ in. in a foot or $\frac{1}{48}$, that is when the cross-section of the gutter is nearly flat, as is frequently the case with lead gutter. When the sides or ends of gutters or flats are formed by walls, the lead should be turned up against the walls of about 6 in. high, and be covered by a separate piece of lead called a *flashing*, the upper edge of which is let into a mortar joint in the wall, and the lower edge covers the top of the gutter lead about 3 in. The joints of flashings, and of hips and ridges, are *lapped joints*; this joint is suitable only for such narrow pieces of lead in vertical or inclined planes. In a ridge, the lead is moulded over a wooden roll fixed to the ridge-piece, and laid over the roof covering on each side; its own weight is sufficient to keep it down without any nails. In hips there is a tendency in the lead to slide down: this might be prevented by the top of every piece being nailed down with ordinary nails, which would be covered by the lap of the piece above it.

In water cisterns and tanks lined with lead the joints must of necessity be made of solder to ensure their being water-tight.

*Solder* used by the plumber is composed of equal parts of lead and tin; it is run into the joint in a molten state, and smoothed down by what is called the *grosing iron*, and finished off by filing and scraping. The joints of the lead are first scraped clean and covered with borax, which easily melting forms a coating to prevent oxidation while the soldering is in process.

*Copper* is in itself very durable as a roof covering, but it is generally used in such thin sheets, on account of the expense of it, that it is liable to become ineffective as a covering before the material is worn out. It is used in England in sheets weighing about 16 oz. a sq. ft.; and in Paris in sheets measuring about $3\frac{1}{2}$ ft. by $4\frac{1}{2}$ ft., and weighing up to 28 oz. a sq. ft. It is not considered necessary in Paris to cover sheets of that thickness with paint or other coating, as the coating of oxide which soon forms on it is a sufficient protection. The mode of fastening copper sheets is similar to that recommended for lead: on account of the thinness of them, they should be laid on boards.

*Zinc* is frequently used for roof coverings on account of its cheapness as compared with lead and copper. It is not so durable as either of them, but being stronger than either it can be used in thin sheets without boards immediately under it; it is used in England in sheets weighing from 12 to 20 oz. a sq. ft., and in Paris in sheets about 6 ft. long and 18 to 30 in. wide, and weighing from 20 to 40 oz. a sq. ft. The thick sheets are said not to require any other coating beyond that of the oxide naturally formed.

*Iron Roofs.*—The facilities now available for the rolling of wrought iron into bars of various cross-sections, enable it to be used with efficiency and economy in the framework of buildings. The metal can be disposed in the cross-section in such a manner as to give the maximum of strength with a given quantity of material, and to give considerable stiffness at the same time, and its elastic force is much greater than that of wood. Therefore, beams of wrought iron can be used with efficiency and economy in larger spans and bearings than of wood: hence, a framework or roof of iron can be made of simpler construction than one of wood: a smaller number of orders of bearers can be employed, and the principal frames or trusses can be more simple and have greater bearings. The general arrangement of a wooden roof has been followed in iron roofs up to a span of about 50 ft.; there are principal trusses, but they are sometimes 15 and 20 ft. apart; the purlins are consequently stronger, and are sometimes framed, and in roofs that are covered with iron or zinc plates, these are frequently laid on the purlins direct. The facility of forming joints in wrought-iron work has caused other forms of trusses to be adopted, which bring the strains more directly on to the bars composing it. The principle of one of the most common of these trusses is, that the beam or bar representing the principal rafter is supported at one or more points by short struts at right angles to it, the ends of which are connected by a continuous bar or rod with both ends of the rafter; the whole strain which passes down the struts is thus transferred to the rafter, compressing it at each end in the direction of its length: owing to the inclination of the rafter there will be an unbalanced force at the lower end, which must be met partly by the wall or column, and partly by a tie-bar or rod connecting the lower ends of the two rafters or some other intermediate points on the rafters. When this tie-bar is placed at an intermediate

point, a cross strain is thrown upon the principal rafter near that point, as in the case of a collar-beam truss.

When the span of the roof is very large, a curved rib or rafter is frequently used, in which the line of pressure of the forces acting on the roof is kept within or nearly within the rib, and the horizontal force at the springing points is provided for by a tie-bar connecting them. This tie-bar being of comparatively small cross-section for its length, is supported by king or queen rods from the rib; sometimes it is curved, or rather polygonal, consisting of straight pieces between the supporting rods, forming a convexity upwards with the object of gaining height in the centre; in all such cases there is a horizontal force not taken up by the tie-bar, which has to be carried either by the rib or by the walls.

The rafter or rib in iron roofs has generally a T cross-section with the flange uppermost, for the convenience of fastening the upper parts of the structure to it; this, however, is evidently not the most effective cross-section, and consequently large ribs are generally made with an I section. Both sections can be rolled in one piece up to 10 in. in depth and ¼ in. thickness of metal, and to a length of 30 ft., without difficulty; above that size they must be built up of flat and angle plates riveted together. Struts are made of wrought iron of T cross-section, and sometimes of two T pieces bolted together flange to flange, forming a + cross-section: sometimes they are of cast iron, in which case they can be made of the best theoretical section, both transverse and longitudinal, to resist compression. Tie-bars are generally rods of a circular cross-section when small, or flat bars when large, any additional required strength in any part being generally obtained by using additional bars of the same cross-section. The same method of obtaining additional strength is adopted generally in the rafters or ribs, in which the thickness of the top flange is generally increased as required, by adding additional flat plates to it. Purlins are generally made either with an L cross-section or a bridge (⌶) cross-section, in both cases for the purpose of fastening other parts to them; for which purpose also the vacant space in each is sometimes filled in with timber. Large purlins are made of timber trussed with iron, or of framed ironwork entirely, and in these cases are sometimes framed in between the principal ribs to gain height and stiffness.

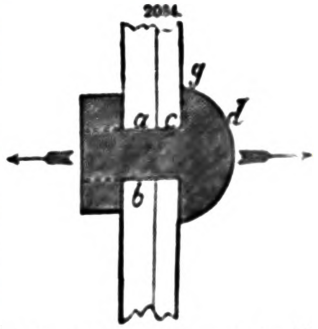
Provision should be made in all large iron framework for expansion and contraction. This is generally done by allowing one end of a truss or frame to be unfixed and free to move horizontally; and to reduce the friction, the bearing surface of the end is sometimes made to rest on iron rollers turning in an iron frame and working in oil: sometimes the end is suspended by or fixed to a short piece fixed to an iron support resting on the wall, which from the action of the two centres of motion admits of a small motion of the whole frame. With short iron beams, such as the girders for small bridges, it is considered sufficient to bed them on lead without other fastening, their own weight being sufficient to keep them in their places.

The bearing surfaces of ironwork are so small that it is impossible to frame them together in any manner depending on those surfaces, as in woodwork. There are two methods commonly adopted for connecting iron bars. 1st, *by large bolts*, which are used when the framework consists of a comparatively few pieces of large cross-section. It is an advantageous method when the bolts are so large that their efficient manufacture can be depended on. 2nd, *by rivets*, which are used when the pieces consist of comparatively thin plates, and are connected by a large number of small bolts called rivets. The joints in ironwork are always the weakest part of the structure: no joint has ever been used, except welding, of which the strength is at all equal to that of the solid part of the pieces joined: then, the manufacture of small bolts cannot be depended on, consequently at the parts of the framework where the greatest strain occurs, the material is weakest; and as those are the points on which oxidation is most likely to occur, it may be expected that the joints of ironwork will give way in course of time before the solid parts of the bars themselves. Therefore, when bolts are so large as to become bars, it is advantageous to use that method; otherwise there is an advantage in riveting, because there is a greater number of individual connections at one joint, and a rivet being hammered in red hot is a more effective connection than a bolt fixed cold, the pieces lie closer together, and upon the whole there are generally fewer separate joints in the whole structure when rivets are used.

2083.

*Bolts* which are subject to a shearing strain, as in Fig. 2083, should not have to bear more than 4 tons to a square inch of each section liable to be sheared. If fixed as in Fig. 2083 it is considered as having six shearing sections, and would therefore bear 24 tons per square inch of cross-section of bolt.

2084.

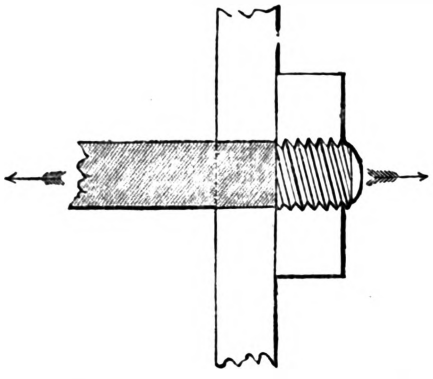



*Bolts* which are subject to direct tensile strain, as in Fig. 2084, should not have to bear more than 5 tons to a square inch on the cross-section at $ab$, or 4 tons a square inch on the cross-section of which $cd$ is the depth, and the circumference of the bolt is the length, which is subject to shearing strain. Consequently, if the bolt is of equal strength throughout, $cd$ must be equal to ⅓rd $ab$.

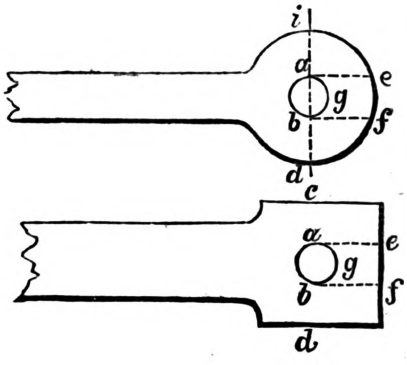
*Screw bolts*, which are subject to direct tensile strain, as in Fig. 2085, should have heads of double the depth of common bolt-heads, because it is estimated that half the resistance to shearing is lost by weakening the metal by the thread of the screw. Consequently, if the bolt is of equal strength throughout, the height of the head or of the nut should be equal to the diameter of the bolt.

*The diameter of the nut* is generally twice that of the bolt itself; but evidently the part *c g*, Fig. 2084, should not be subject to a greater pressure per square inch than the *safe* crushing strain of the metal.

2085.



2086.

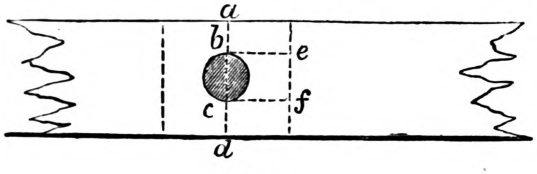



*Links*, that is to say, two or more flat bars connected together by a bolt passing through their ends, and subject to tensile strain, should have those ends enlarged, as in Fig. 2086, so that the sum of the areas of the cross-sections *a c* and *b d* shall be equal to the area of the cross-section of the body of the link. The end is also subject to a shearing strain on the sections *a e* and *b f*, the areas of the cross-sections at each of those two points should therefore be calculated so as to have a strain of not more than 4 tons a square inch on them. Also, the compressile strain on the surface *a g b* should not exceed 5 tons the square inch.

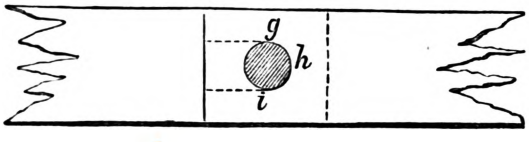
*Rivets.*—The dimensions of rivets and of the plates at the joint may be calculated by the same rules as for single bolts. If it is a joint subject to tension, as in Fig. 2087, the effective strength of the joint and of the plate is the resistance of the cross-sections *a b* and *c d* to tension, and of the cross-sections *b e* and *c f* to shearing. If it is a joint subject to compression, as in Fig. 2088, the effective strength is the resistance of the section *g i h* to compression. Hence, in a *tensile lap joint* the size of the rivets should be as small as possible, and the sections of the parts *a b c d* as large as possible; and in a *compressile lap joint* the size of the rivets should be as large as possible.

*Lap joint* is the name given to a riveted joint when the plates overlap each other. In a *single rivet* lap joint, as in Fig. 2089, the whole tensile or compressile strain being divided amongst the spaces between the rivets determines the interval of them. And the whole shearing strain being divided amongst the sections *a b*, *c d*, &c., determines the amount of overlap. Fairbairn considers that the strength of such a joint under tension is only 0·56 of that of the solid plate of the same general cross-section.

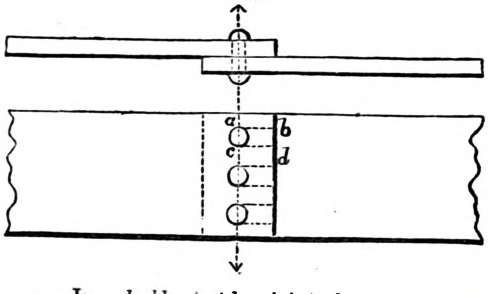
2087.



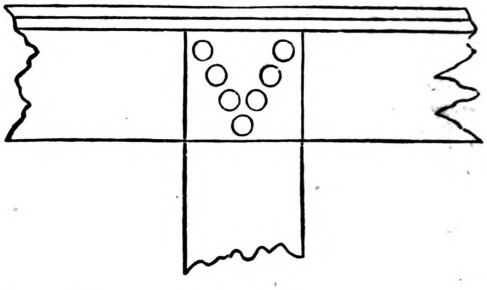

2088.



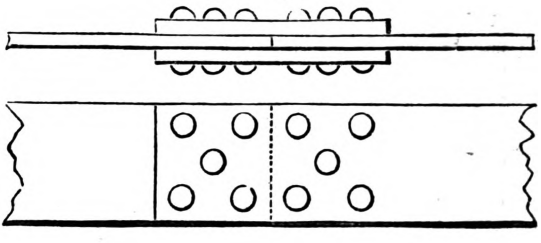

2089.




2090.



2091.



In a *double rivet* lap joint the amount of overlap and the intervals between the rows of rivets both ways, and the size of the rivets, are all determined by the above considerations, and by the rules for bolts. Fig. 2090 shows the joint recommended by Humber for tensile strains

Fig. 2091 shows the joint he recommends for compressive strains.

In practice the diameter of the rivets is generally made a little more than the thickness of the plate, and the interval is from 2 to 4 times the diameter, according to the closeness of the joint required.

The practice in H.M. Dockyard at Chatham, in the construction of iron ships, is to use rivets rather larger in diameter than the thickness of the plate, and at intervals from 2 to 4 times the diameter. Thornton states that a water-tight joint can be formed with single riveting at intervals of 4 diameters; double riveting is commonly used, the first row being placed at a distance of at least one diameter (of rivet) from the edge of the plate, and the second row at about 3 diameters from the first. These rules determine the length of what is called the butt-plate, or fishing-piece. The rivets in the second row are placed directly opposite those in the first row, and not diagonally opposite the spaces. In all exterior plates the outer rivet-holes are countersunk and the rivets hammered flush.

Bolt-nuts are generally made in depth equal to the mean diameter of bolt, and india-rubber washers of about $\frac{1}{3}$ that thickness are used with bolts through thick plates.

The experiments in the testing-house of Chatham Dockyard show that if the total area of the rivets is equal to the area of the cross-section of plate at one row of rivet-holes, the strength of the rivets to resist shearing will be greater than that of the plate to resist tension; also, that the punching of holes in steel or hard iron injures the metal round the holes, so that the plate is considerably weakened at that part. Rivets with hammered heads are more liable to leak than with heads rounded in a swage, and the latter than countersunk conical heads: countersinking should always be drilled; and rivets fixed cold are tighter than those fixed hot.

The following extracts from the Regulations of the Society of Underwriters at Liverpool for Iron Ship Building show the practice in that trade for riveting plates:—

| | Sixteenths of an inch. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Thickness of plates .. .. | 5. | 6. | 7. | 8. | 10. | 12. | 13. | 14. | 15. | 16. |
| Diameter of rivets .. .. | 8. | 10. | 12. | 13. | 14. | 15. | 16. | 18. | 19. | 20. |

Rivet-heads should be thin, and rivet-necks, under the heads, should be bevelled to fill the countersink formed in punching. All riveted seams and butts to be laid up quite close, so as to prevent the introduction of the thinnest knife used for trying riveted work.

Every hole requiring to be countersunk must be countersunk quite through the plate. Each rivet to fill the hole and to be laid up close round the head, and when finished to be flush and fair, neither projecting above nor sinking below the surface of the part through which it passes.

All double riveting to be in parallel rows, or what is termed chain riveting. All butts to be double riveted. Breadth of lap in seams and butts, for double riveting, to be $5\frac{1}{4}$ times the size of the hole punched. Rivets to be 4 diameters apart, from centre to centre, longitudinally in seams and butts. Rivets in framing to be 8 times the size of the hole punched, apart.

Iron decks to have their butts treble riveted amidships.

*Extract from Lloyd's Rules.*—Rivets not to be nearer to the butts or edges of the plating, or of any angle iron, than a space not less than their own diameter, and not to be farther apart from centre to centre than 4 times their diameter, or nearer than 3 times their diameter. In single riveting the overlap is not to be less in breadth than 3 times the diameter of the rivets. No rivet to be less than $\frac{5}{8}$ in. in diameter.

TABLE OF THE WEIGHT OF ROOF COVERINGS AND THE SLOPE FOR THEM SUITABLE FOR THE ENGLISH CLIMATE, FROM TREDGOLD.

| Material. | Weight a square of 800 sq. ft. lbs. | Slope. |
|---|---|---|
| Ordinary slates .. .. .. | 500 to 900 | .. .. $26\frac{1}{2}°$ |
| Large slates .. .. .. .. | 1120 | .. .. $22\frac{1}{2}°$ |
| Plain tiles .. .. .. .. | 1780 | .. .. 50° |
| Pantiles .. .. .. .. .. | 650 | .. .. 50° |
| Thatch .. .. .. .. .. | same as slates | .. .. 45° |
| Copper .. .. .. .. .. | 100 | .. .. 3° 50′ |
| Lead .. .. .. .. .. | 700 | .. .. 3° 50′ |

The weights here given include the covering and the immediate bearers underneath, but no rafters or other framework. An allowance for the pressure of wind and snow must be made in addition. Tredgold recommends that the former should be calculated at 40 lbs. a square foot of horizontal pressure on a vertical surface.

*Floors.*—Under this head we include all kinds of floors and pavements of stone and wood, both the framework and the floor covering. The technical builder sometimes includes under the name flooring only the boards or covering; but it is evidently more correct to treat under one head all the parts of those platforms which form the living places in houses, of whatever material they are.

The same general principles of framing apply to all floors of wood framing as were applied to roofs; being simplified in the case of floors, because they are almost always flat. The problem in floors of this class is to provide the smallest number of bearers that will carry an effective floor covering with the greatest economy and stiffness.

*Single Floors.*—The simplest description of wooden floor, when there is only one order of bearers supporting the boards, is technically called a *single floor*, and the bearers are called *joists*. Tredgold recommends that single joisting should not be applied to a bearing above 15 ft., on account of the deflection, which then becomes so great as to be inconvenient. As a joist has only to bear perpendicular transverse strain, the deeper it is the better; but such beams have a tendency to buckle or turn over on their sides, and to counteract this, they should be strutted against each other; such strutting may be composed of short pieces of wood nearly the depth of the joists, and fitted in at

right angles to them, and moderately tight, and nailed, not morticed. Tredgold recommends that there should be a row of strutting when the bearing of the joists is more than 8 ft., and two rows of struttings to bearing above 12 ft., and an additional row for every additional bearing of 4 ft. He mentions an experiment made by Professor Robison to illustrate the strength of single floors of two models, one representing a single and one a double floor, both 18 in. square, and containing the same quantity of wood. The former broke with a load of 487 lbs., the latter with a load of 327 lbs.

Joists are generally laid at a central interval of 1 ft., when covered with boards, because floor boards are not generally more than 1½ in. thick; and with a much greater bearing than 12 in. they would deflect considerably.

The minimum thickness for a joist is 2 in., to allow hold for the nails of the boards without splitting the timbers.

They are generally laid on the wall-plates, and not notched or framed. The wall-plates extending all round the walls are very frequently laid in a kind of groove left in the brickwork; and, therefore, the ends of the joists enter into the walls, a practice which tends to cause decay in the wood, besides weakening a thin wall considerably. The more effective method is to *corbel* out the wall to form a support for the wall-plates, and so keep the joists clear of the main wall. In ground floors this is accomplished by a set-off increasing the thickness of the wall.

Ceilings that are covered with lath and plaster, which is the method commonly used in England, are supported by *ceiling joists*, which are notched and nailed at right angles to the joists or beams of the floor above. The ceiling joists should not have more than 10 or 12 in. central interval, otherwise the lath and plaster would be liable to break from its own weight. In a single floor, in order to check the passage of sound from one room to the other, it is usual to make every third or fourth joist about 1½ in. deeper than the others, and to nail the ceiling joists to these only, thus diminishing the points of contact between the floor boards and ceiling. Tredgold recommends that no ceiling joist should have a greater bearing than 10 ft.

The ceiling joists should not be less than 2 in. thick, on account of the lath nails.

*Framed Floors.*—The method most recommended by Tredgold and others for introducing a second set of bearers to stiffen a floor when the breadth or span exceeds 15 ft., is by placing large beams across the breadth at suitable intervals, and notching the joists on to these. These large beams are called *girders*. Tredgold assumes the central interval to be generally 10 ft.; but that must vary according to circumstances. One advantage of the framed floor is that the ends of the girders can be supported easily by corbels projecting from the wall, a template being introduced under each to distribute the weight. If, however, the ends of the girders are let into the main wall, an open space should be left round them for ventilation, covered with a flat stone or arch to carry the wall above. Girders should have a bearing from 9 to 13 in. on the wall. Such floors of two orders of bearers are technically called *double floors*.

When the breadth of the floor is above 30 ft. it is difficult to procure timber of the necessary size for girders, and the deflection of them would be considerable: hence arose the practice of trussing or framing wooden girders, on which great ingenuity was expended before iron was used, with the object of reducing the total depth of the truss as much as possible, to keep down the depth of the whole framework of the floor. Tredgold considered that no trussing which is contained within the depth of the solid beam itself can be depended on, on account of the injury to the fibres of the main beam by the framing; also, that the practice of *cambering* a beam, that is, so fixing the framework that the main beam without any load on it assumes a curved form, convex towards the load, so cripples the fibres that the additional resistance obtained by it is apparent rather than real The method generally recommended for floors of such great breadth before iron was used was to place large trussed girders at about 10 ft. central intervals, and to frame in other girders between them at about 6 ft. central interval, and to notch the joints on these last, the object of framing the intermediate girders between the others instead of notching them on being to save total depth in the floor. These intermediate girders are technically called *binding joists*, and the common joists are in this case called *bridging joists*, and the whole is called a *framed floor*. The ceiling of the room below such a floor is supported by common ceiling joists fixed to the binding joists of the floor, or to others fixed to the girders for the purpose. But Tredgold considers it would probably make a stronger floor, though of greater total depth, to place girders at 5 ft. interval, and omit the binding joists altogether.

He recommends that a wooden floor should be laid with a slight camber upwards (about ⅜ in. in 20 ft.), and especially ceiling joists, with the object of allowing for settlement from shrinking.

The following practical rules for the sizes of the beams of ordinary wooden floors are taken from Tredgold's Carpentry. They are most of them founded on the same assumption he adopted in the case of roof beams, namely, that the safe deflection to be allowed in floor beams should vary inversely as the length between the points of support; and as mathematically the deflection is proportional to $\frac{l^3}{b\,d^3}$, Tredgold's law reduces the formula for practical purposes to $\frac{l^2}{b\,d^3}$, in order that the stiffness may be directly as the length. Then by assuming a given deflection to be allowed in a given floor, and a fixed method of arranging the beams, he obtains a constant coefficient for each beam applicable to all similar floors.

*Common or Single Joists.*—$d = 2{\cdot}2\sqrt[3]{\frac{l^2}{b}}$ $\left\{\begin{array}{l}\text{where } d = \text{depth} \\ b = \text{breadth} \\ l = \text{length between bearings}\end{array}\right\}$ of beam in inches, of ditto in feet,

the central interval of joists being assumed to be 12 in.

*Binding Joists.*—$d = 3{\cdot}42\sqrt[3]{\frac{l^2}{b}}$, the central interval of joists being assumed to be 6 ft.